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ANAEROBIC-AEROBIC PONDS FOR BEET SUGAR WASTE TREATMENT

William J. Oswald, et al

Beet Sugar Development Foundation

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Environmental Protection Agency

February 1973

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16. Abstract

Sugarbeet factory transport (flume) water wastes were treated in pilot-sized anaerobic, facultative and aerobic ponds to remove BOD. Physical, chemical and mechanical data were collected on the performance of each pond which showed cause for abandoning the facultative phase of treating. BOD removal in the anaerobic pond was a linear function of the BOD loading and up to a loading of 2,000 pounds of BOD per acre per day, 80% removal was accomplished with the assistance of mechanical aeration. The algae (aerobic), pond was mixed by means of four 12,000 gpm propeller pumps. Some unseparated algae pond effluent was recycled to the anaerobic pond providing organic nitrogen, phosphorus and "seed" for the microbial transformations. Additional nutrients were required for maximum performance. The system was effective in converting soluble BOD to insoluble BOD. The report contains 42 figures and 11 tables which show potential commercial application of certain segments of the processes investigated. (M)

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17b. Identifiers

Sugarbeet Waste Treatment, Anaerobic Pond, Facultative Pond, Aerobic Pond, Algal Growth Nutrient Addition, Odor Control.

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Grant Nos. WPD 93-03 and 93-04

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ABSTRACT

Sugarbeet factory transport (flume) water wastes were treated in pilot-sized anaerobic, facultative and aerobic ponds. Physical, chemical and mechanical data were collected on the performance of each pond which showed cause for abandoning the facultative phase of treating. BOD removal in the anaerobic pond was a linear function of the BOD loading and up to a loading of 2,000 pounds of BOD per acre per day, 80% removal was accomplished with the assistance of mechanical aeration. The algae (aerobic) pond was mixed by means of four 12,000 gpm propeller pumps. Some unseparated algae pond effluent was recycled to the anaerobic pond providing organic nitrogen, phosphorus and "seed" for the microbial transformations. Additional nutrients were required for maximum performance. The system was effective in converting soluble BOD to insoluble BOD and, had filtration or separation been applied to effluents, BOD removal would have been 98 percent. Loadings above 1,000 pounds of BOD per acre per day generally are not permissible because of odor production and high effluent BOD.

Key Words: Sugarbeet wastes, anaerobic pond, facultative pond, aerobic pond, algal growth, nutrient addition, odor control

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SECTION I

CONCLUSIONS

Because of the large quantities of mud and extraneous vegetation contained in beet flume water, screening and short-term sedimentation are absolute requirements for pretreatment of sugarbeet waste. The degree of sedimentation should be limited in time to a few hours, however, since carry-over of some mud seems to have a beneficial effect on fermentation in an anaerobic beet waste pond.

Even after screening and short-term sedimentation, sugarbeet waste is so variable in pH, BOD, and composition that short detention period biological processes such as activated sludge, trickling filter, and algae ponds cannot be effectively employed as the initial process in a treatment system.

With mechanical surface aeration at about 300 lbs of O_2 per day, an anaerobic pond 14 ft deep and one acre in surface area may be loaded at a rate of 1000 lbs of ultimate BOD per acre per day without excessive odor.

When factory waste is passed through an anaerobic pond, the discharge has a more uniform pH and a much lower and more uniform BOD than does the original waste. In spite of its lower biodegradeability, it is by virtue of its uniformity, more subject to effective short detention time secondary biological treatment.

Following passage of waste through an anaerobic pond, the pond effluents are devoid of oxygen, high in a turbidity consisting of microorganism and colloidal-reduced substances such as metal sulfides, high in BOD, and are malodorous. Effluents of this quality must be subjected to aeration treatment before storage, discharge to the aquatic environment or reuse.

Aerobic treatment subsequent to adequate anaerobic ponding may involve photosynthetic oxygenation, simple ponding in a facultative pond, or possibly mechanical aeration. The last alternative has not been extensively explored. In the case of photosynthetic oxygenation with algae removal, loadings of 200 lbs of ultimate BOD per acre per day would be acceptable, whereas in the case of facultative ponds, without algae removal, loadings of 100 lbs of ultimate BOD per acre per day are the most that can be recommended because of odors. In the case of mechanical aeration, it seems likely that to maintain a 4 mg per liter DO residual, 1 horsepower would be required for each 40 lbs of daily ultimate BOD applied to the aeration pond.

As shown in Figure 6, recirculation of secondary pond effluent to the anaerobic pond influent probably had a beneficial effect upon overall treatment. The effect probably is related to nutrient return and "seeding". A recirculation rate of ½ to 1 Q should be adequate to achieve these benefits.

If recovered waste water from an aeration pond is to be rendered suitable for discharge to the aquatic environment or for recycle and reuse in a beet sugar factory, it should be subjected to filtration or separation to remove clay turbidity and bacterial and algae cells. The removal of these substances following anaerobic-aerobic treatment produces a final effluent of fairly high quality having a BOD of less than 2 mg per liter. Following passage through the anaerobic pond, nutrient supplementation with ammonium-nitrogen at 20 mg per liter and phosphate at about 10 mg per liter is essential for adequate aerobic biological treatment. Because of losses of nitrogen which were found to be substantial in the anaerobic pond, nitrogen should be added following passage of the liquid through the anaerobic pond. The best point for addition of phosphate requires additional study.

Treatment to remove dissolved nutrients will not be required if nutrient supplementation is carefully controlled. However, to meet the quality standards set up by most of the states, suspended solids will have to be removed from the final effluent by filtration or by some other separation device prior to discharging the effluent into the environment.

The problem of odors in beet waste ponds can only be solved by avoiding overloading of ponds, by providing sufficient treatment area, sufficient aeration, and by providing nutrient supplementation. Anaerobic pond loadings should not exceed 1000 lbs per acre per day, and aeration should be applied at the surface of the anaerobic pond to the extent required to prevent odors. Secondary aerobic ponds should be loaded at not more than 200 lbs per acre per day, and supplementary aeration in the form of flow mixing or possibly surface aerators should be provided. Final effluent must be filtered or otherwise separated to produce a clear supernatant if it is to be suitable to meet most discharge requirements.

SECTION II

RECOMMENDATIONS

A full-scale project should now be developed in California to handle the entire output of a 4 to 5 K-ton factory to demonstrate the feasibility of anaerobic-aerobic ponding for nuisance-free treatment of beet sugar factory wastes. The system should include prescreening and short-term sedimentation, anaerobic ponding with maximum loads at 1000 lbs per acre per day, and have surface aeration for odor control. The anaerobic pond should be followed by aeration systems which include aerobic ponds at loadings of about 200 lbs per acre per day. In the aerobic ponds a regimen of eddy diffusion, supplementary aeration, and photosynthetic oxygenation should be applied. Recirculation of secondary effluent to the influent should be supplied. The system should include screening of recycled water, nutrient supplementation in the algae or aeration pond, and filtration of final effluent. Data collection should include all parameters in this study and in addition those pertaining to chlorides and alkalinity. The system should be installed in a factory which does not produce Steffens waste, and which has separate disposal of all human wastes.

SECTION III

INTRODUCTION

HISTORICAL

The first of this series of two studies of large-scale pilot plant treatment of beet sugar flume water waste was initiated on June 1, 1965 and terminated on May 31, 1967. The second study, to be summarized in this report, was initiated on June 1, 1967 and was terminated on May 31, 1969. The major objective of the 1965 to 1967 study was to demonstrate the feasibility of utilizing a series of three ponds -- "anaerobic", "facultative", and "algae" to stabilize beet sugar factory waste water by decreasing the odor of waste ponding and rendering the final effluent sufficiently low in BOD for discharge to the aquatic environment. To accomplish this demonstration, a six-acre pilot plant was constructed at the Holly Sugar factory, Tracy, California. The pilot plant consisted of a pumping station, a screening system, a settling tank, a metering station, a one-acre by 14 ft deep anaerobic pond, a two-acre by seven-ft deep facultative pond, and a three-acre by three-ft deep algae pond. A description of this pilot plant and of the operational data are given in detail in Progress Report III (1) which covered the first series for the period June 1, 1965 to May 31, 1967. Inasmuch as this report is intended to cover only the 21-month period, June 1, 1967 to March 1, 1969, information given in Progress Report III will be repeated only as required for clarity.

One of the conclusions of Progress Report III was that it is not possible to operate a ponding system for flume water wastes without odor in the absence of relatively large quantities of molecular oxygen. Thus, it was concluded that systems involving aeration by mechanical aerators or by photosynthetic oxygenation should be investigated. The second series of studies involved an exploration of these alternatives.

PREVIOUS WORK

The work done in the first research period was mostly concerned with the anaerobic phase of the anaerobic-facultative-aerobic lagoon complex, and hence the research was directed towards determining the extent of treatment that could be accomplished without special design features to emphasize aeration or algal production. In line with this emphasis, operational features such as loading and recirculation and their relationship to treatment efficiency were extensively studied.

Results obtained in the research, cf. Progress Report III (1)

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and Tsugita, et al. (2), furnished ample evidence for believing that the basic principles involved in treatment of sugarbeet waste waters by lagooning in an anaerobic-facultative-aerobic lagoon complex are applicable to real systems, but by no means constitute an optimum system. For example, conflicting information was obtained on recirculation. The importance of recirculation is primarily related to conveyance of oxygen, "seed", and nutrients into the primary stages of the system; in dilution of the influent waste with recovered water; and, in forcing stronger wastes forward in the system, thus possibly increasing the efficiency of secondary units. There is some evidence from the initial studies that the optimum rate of recirculation changes with changing conditions in the ponds; and that under some conditions, rates in excess of one or two times the influent volume may be undesirable. The results further indicated that a controllable growth of algae in the aerobic pond is dependent either on controlled mixing or on some presently unknown factor.

Despite generally favorable results, the three-pond system as it was applied in the first study would not be suitable for a routine application to factory wastes simply because waste treatment was not accomplished to the extent required for an odor-free operation, or for an operation in which an effluent would have to meet reasonably strict discharge requirements. The reason for these shortcomings can to some extent be ascertained from a consideration of the results. Most of the BOD, COD, nitrogen, and other removals were accomplished in the anaerobic pond; whereas the facultative and aerobic ponds contributed only slightly to the total treatment and thus were apparently underloaded. While substantial, the extent of treatment accomplished in the anaerobic pond was far from that needed for full treatment to an effluent acceptable in the aquatic environment. However, had the remaining two ponds been operating at their potential capacities, the total treatment undoubtedly would have been satisfactory--judging from the past experience with such pond systems in domestic waste treatment.

A question thus remained: Why did the facultative and aerobic ponds apparently fail to make a substantial contribution to treatment? Another problem was that algae failed to grow under certain conditions prevailing in the ponds in which they were supposed to grow, thus limiting oxygenation. As the system was designed to operate, algae were to fill a very important role in that they were to supply the oxygen removed in the aerobic pond and in the surface strata of the facultative pond. Availability of photosynthetic oxygen would have made possible a degree of BOD removal not possible in the absence of oxygen. (An additional function of algae was intended to be the removal of algal nutrients and their return with recirculant to the anaerobic pond.) The answer to the question -

why the algae failed to grow in sufficient quantity - is believed to be due to a lack of certain required nutrients and obstruction of light by bacterial and sulfide turbidity, as well as an absence of mixing.

In the first two years of research, no provision was made either to provide special nutrients or for mixing the algae-producing or aerobic pond, although past experience with sewage ponds furnished definite reasons for believing mixing is an important factor in algae growth and production. However, inasmuch as the evidence for the need to mix had not been demonstrated in the case of beet sugar flume wastes, and inasmuch as the aim in designing any industrial waste treatment system is to attain satisfactory performance at a minimum capital and operational cost, provision for mixing the aerobic pond was deliberately omitted in the first design in the hope that it might not be essential. It was also considered desirable to learn just what could be accomplished without mixing. Experience gained in the prior studies with domestic sewage had indicated that although algae grow in ponds without mixing, mixing is essential to the sustained and controlled production of algae.

A further consideration of the first period results brought to light several important pieces of information lacking in the research, and which had to be obtained in these studies if full utilization of the system were to be attained in practice. For example, more information was needed about the sensitivity of the principal microorganisms involved in the process, i.e., their environmental limits; about the mechanism of coliform and pathogen die-off; about the mode of $SO_4^=$ removal--whether or not it is biological, chemical, or physical, or a combination of these, and about the factors involved in odor elimination and COD and BOD reduction. It was also deemed important to determine the independent role of the facultative pond in the system and the independent role of the algae pond.

Inasmuch as the results obtained in the first research period indicated that the satisfactory performance of the facultative-aerobic phases is essential to the efficient function of the anaerobic-facultative-aerobic complex as a whole, the principal objective of the proposed research was to determine the effectiveness of the system with either the facultative or the aerobic ponds operating in series with the primary or anaerobic pond. Also, because one of the functions of the secondary ponds is aeration, a study of mechanical aeration as compared with natural aeration was deemed desirable.

Experience in other studies of natural aeration as well as that gained in the first study period without mechanical aeration showed that algae constitute an important feature in the anaerobic-facultative-aerobic lagooning system for treating any waste, and particularly sugarbeet waste waters, and that algae cannot be produced in the quantity required to fulfill their role without at least a minimal provision for mixing the aerobic pond. Because of the importance of these two (algae production and mixing), another objective of the study was the determination of the effect of mixing and, of course, other environmental factors on algae production in the system, as well as the consequent effect on the treatment performance of the complete pond complex.

Among the specific operational factors considered for study with respect to the system as a whole and to its constituent units were recirculation rate and flow pattern, mixing velocity, frequency and duration, retention period, depth, and point of introduction of influent and removal of effluent. However, because of operational difficulties and time limitations, it was not feasible to explore all of these factors. No attempt was made to vary natural environmental factors, but data were collected on light, temperature, and solar energy so that correlations could be made between observed natural factors and accompanying system performance should correlations exist.

Beet sugar flume water is a waste of moderate strength and high variability. Studies made in the first research period showed that it is high in carbon and BOD, that the 5-day BOD is about 67 percent of the COD, indicating a relatively high biodegradability of the nutrients. The waste is often deficient in nitrogen and phosphorus and consequently is often moderately slow to decompose biologically. The waste may contain artificially introduced compounds specifically designed to retard biological growths, particularly when cooling towers are employed for condenser water and condensate is included in the waste stream. The waste always contains substances which become volatile and malodorous during anaerobic decomposition. Under anaerobic conditions, hydrogen sulfide is often emitted. Moreover, judging from the odors, volatile acids, alcohols and other aromatic substances are characteristically produced.

Many beet sugar factories in a warm climate such as prevails in California and Texas have two operational periods (campaigns) of about four months each year; whereas, factories in cold climates such as are characteristic of Colorado and Idaho have a single yearly campaign beginning in October and extending through March. During the fall in warm climates and during the winter and spring in cold climates, stockpiled beets rot and release organic matter as compared to that taking place with fresh beets. The release of organic matter results in an increased strength of the wastes. Regardless of climate, start-up problems are always encountered.

Processing capacities of modern beet sugar factories range from 1,000 to 10,000 tons of beets per day. For each ton of beets processed, from 500 to 2,000 gallons of excess water containing 500 to 2,000 mg per liter of BOD are produced. Highest BOD values are associated with greatest reuse of water. Hence, factories which discharge only 500 gallons per ton of beets may have waste waters of 2,000 mg per liter BOD; whereas factories which discharge 2,000 gallons per ton of beets may have wastes of 500 mg per liter BOD. Depending on operations and time of year, a beet sugar factory may waste from 5 to 20 lbs of BOD in flume water per ton of slice, the average probably being about 8 lbs. Thus, a factory slicing 4.5 kiloton (about average), will discharge 36,000 lbs of BOD per day.

NATURAL SURFACE AERATION

In a quiet pond, natural surface aeration will contribute about 20 lbs of oxygen per acre per day to the impounded water. If one were to assume that beet sugar flume water were as easily treatable as domestic sewage (which is decidedly not the case), one would expect the aerial requirement for simple surface aerated ponds to be on the order of 0.40 acres per ton of slice. Thus, an average factory with 4.5 KT of slice would require about 1,800 acres of natural disposal area. If this area or its equivalent in designed facilities were not provided by the factory and the wastes were put into the natural aquatic environment, at least 1,800 acres of that environment would undergo some degree of dispoilment and all opportunity for water reclamation would be lost. If the area of land dispoiled is to be decreased, a more sophisticated means of aeration or treatment would be required. Water losses due to evaporation and percolation depend upon local conditions such as rainfall, evaporation, and soil characteristics. However, such losses usually amount to about 2 million gallons per acre per year, and hence in the case of an 1,800 acre pond, losses would exceed the loading velocity for this rate which would be about 0.58 million gallons per acre per year. Thus, if ponds were built of sufficient size to permit natural aeration to satisfy the applied BOD, they would be so large as to remain dry and non-operational much of the year. On the other hand, if it is assumed that the hydraulic loading were sufficiently large to insure that the ponds would be wet the year around, the areal requirement could be reduced to 0.115 acres per ton of slice; and the corresponding oxygenation load would average

70 lbs per acre per day with peaks up to 110 lbs per acre per day. This degree of loading would far exceed the rate of natural aeration and consequently would demand a contribution of oxygen from external sources at rates on the order of 50 to 90 lbs per acre per day. Such a contribution is feasible from natural photosynthesis provided light and temperature permit. It probably is the maximum that can be attained without special provision for mixing and other treatments. If land use is to be further curtailed, special systems must be employed.

In summary, the work done previously has shown that substantial reductions in solids, BOD, and nutrients may be attained in simple ponds; but that land use, effluent BOD and odor would be excessive. On the other hand, the first series of studies showed that by using an anaerobic pond in series with other ponds, land use could be curtailed. However, effluent BOD and process odor would still be excessive.

The specific purpose of this second study was to explore mechanisms to improve pond design and operation to increase the rates of BOD and odor removal and to further explore methods of decreasing land requirements. Another purpose of the work was to derive design criteria for systems of ponds which would have predictably satisfactory performance over a range of environmental conditions; and which could therefore be applied to meet discharge specifications in a variety of climates.

SECTION IV

EXPERIMENTAL

During the 1967 to 1969 period, three types of systems were studied: an anaerobic pond with aeration, an anaerobic pond with aeration in series with a facultative pond, and an anaerobic pond with aeration in series with a photosynthetic algae pond.

THE PILOT SYSTEM

A detailed description of the overall system including copies of the original blue prints was presented in Progress Report III (1) and modifications of the system for the anaerobic, the anaerobic-facultative, and the anaerobic-algae system to be reported herein are shown in Figure 1.

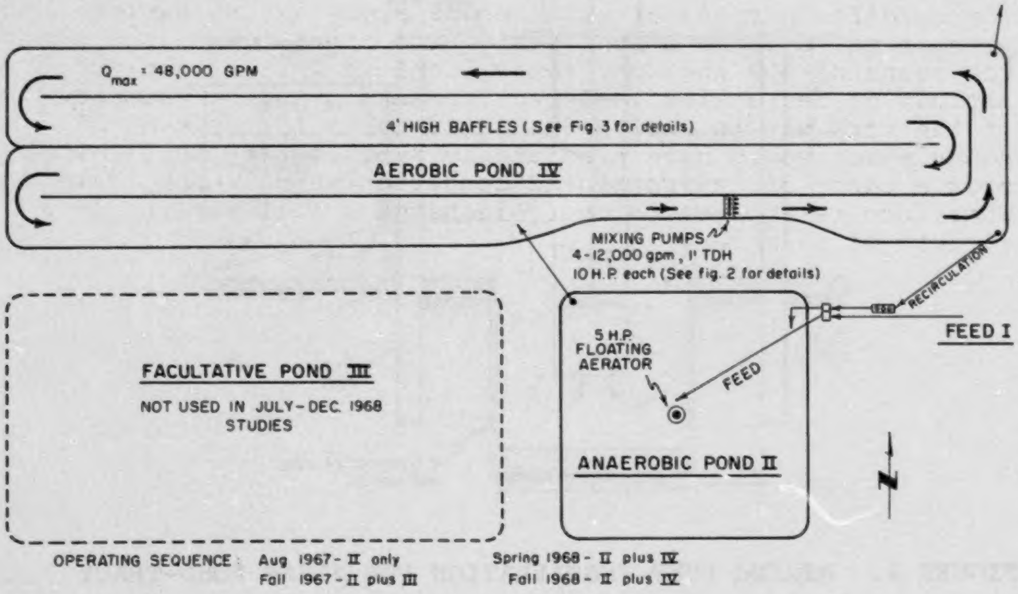
Q_max = 48,000 GPM
4' HIGH BAFFLES (See Fig. 3 for details)
AEROBIC POND IV
MIXING PUMPS
4-12,000 gpm, 1' TDH
10 H.P. each (See fig. 2 for details)
RECIRCULATION
FEED I
5 H.P.
FLOATING
AERATOR
FEED
FACULTATIVE POND III
NOT USED IN JULY-DEC. 1968
STUDIES
ANAEROBIC POND II
N
OPERATING SEQUENCE: Aug 1967 - II only
Fall 1967 - II plus III
Spring 1968 - II plus IV
Fall 1968 - II plus IV

FIGURE 1. SHOWING LAYOUT OF PONDS, ARRANGEMENT OF BAFFLES AND MIXING PUMPS IN AEROBIC POND

In brief, as shown in Figure 1, following DSM screening and one to two hours of sedimentation, waste was introduced into the anaerobic pond together with recirculant, and then was discharged into either the facultative or into the elongated mixing pond at the discharge end of the mixing pumps and because the three pond regimen had been explored previously in Progress Report III. During tests with the anaerobic-facultative system, recirculation was not used because the algae pond was out of operation.

The low-head propeller pumps used to mix the algae pond Were designed for 12,000 gallons per minute each and are shown schematically in Figure 2. The four propeller pumps require about 40 HP to recycle and maintain algae in suspension and theoretically to provide nutrients for algae from the water soil interface, where facultative bacterial action is near its maximum, and to prevent thermal stratification. Details of the baffle construction designed to provide uniform flow in the algae pond are shown in Figure 3.

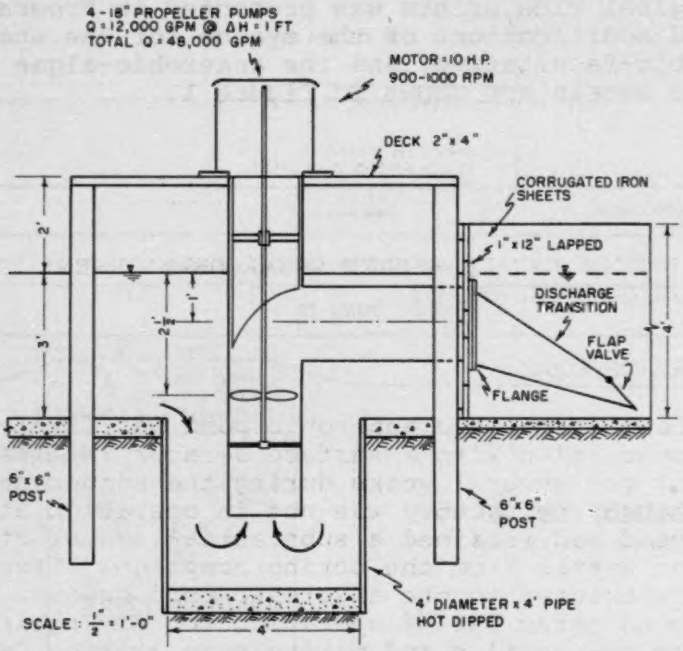
4 - 18" PROPELLER PUMPS
Q = 12,000 GPM @ ΔH = 1 FT
TOTAL Q = 48,000 GPM
MOTOR = 10 H.P.
900-1000 RPM
DECK 2" x 4"
CORRUGATED IRON SHEETS
1" x 12" LAPPED
DISCHARGE TRANSITION
FLAP VALVE
FLANGE
2'
3'
1'
2'-1/2"
4'
6" x 6" POST
6" x 6" POST
4' DIAMETER x 4' PIPE HOT DIPPED
SCALE : 1/2" = 1'-0"
4'

FIGURE 2. MIXING PUMP INSTALLATION FOR ALGAE POND-TRACY

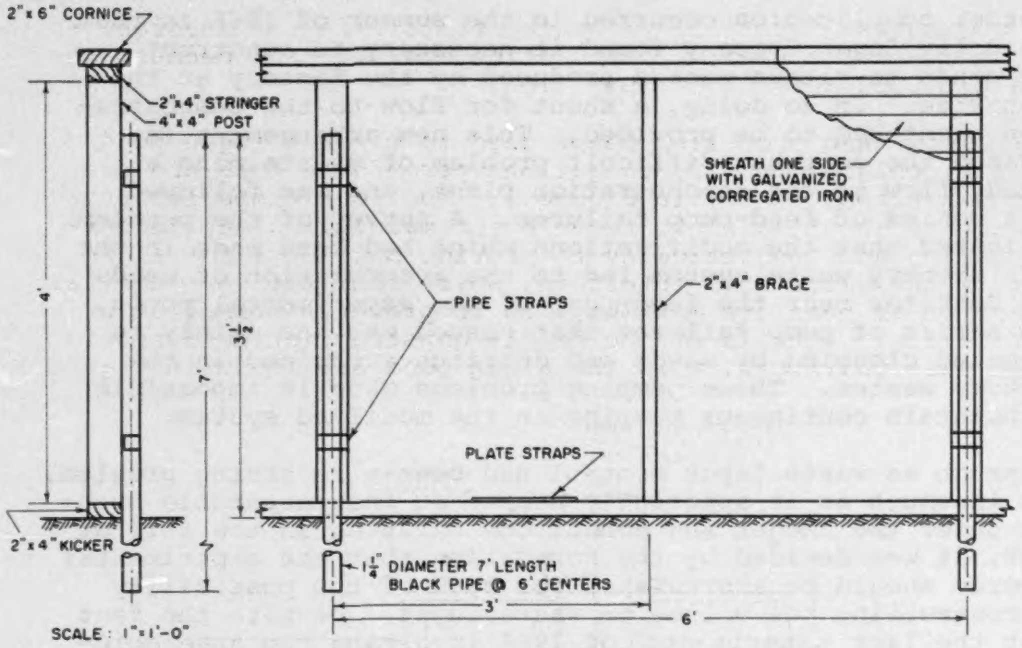
2" x 6" CORNICE
2"x4" STRINGER
4"x4" POST
SHEATH ONE SIDE WITH GALVANIZED CORREGATED IRON
2"x4" BRACE
PIPE STRAPS
PLATE STRAPS
2"x4" KICKER
1 1/4" DIAMETER 7' LENGTH BLACK PIPE @ 6' CENTERS
4'
7'
3 1/2"
3'
6'
SCALE : 1"=1'-0"

FIGURE 3. BAFFLE DETAIL - BEET SUGAR DEVELOPMENT FOUNDATION ALGAE POND-TRACY

EXPERIMENTAL PROGRAM

In the current series the anaerobic pond was first operated alone in conjunction with a surface aerator (Welles Products Corporation) for several weeks during the summer period of 1967. Although the factory was not in operation at this time, the pond had retained a substantial amount of oxidizeable organic matter from the spring campaign. Treatment had to be restricted to the anaerobic pond because the algae pond had to be taken out of operation for drying in order to construct the baffles and mixing pump station described in the preceding paragraphs.

When factory wastes became available during the 1967 fall campaign, drying and reconstruction of the algae pond had not been complete. Therefore, an anaerobic-algal pond plus facultative system was operated for the balance of the 1967 fall campaign. The facultative pond shown dotted in Figure 1 was used. In the spring of 1968, experiments were conducted with the surface-aerated anaerobic pond in series with a pump-mixed, high-rate algal pond. It was found that severe leakage occurred under the baffles of the algal growth pond, and consequently, the system was modified during the summer of 1968 to prevent leakage and improve the flow pattern.

Another complication occurred in the summer of 1968 in that the Holly Sugar Company found it necessary to construct new ponds to retain wastes produced by the factory at the test site. In so doing, a shunt for flow to the demonstration plant had to be provided. This new arrangement increased the somewhat difficult problem of maintaining a steady flow to the demonstration plant, and was followed by a series of feed-pump failures. A survey of the problem indicated that the modifications which had been made in the main factory waste system led to the accumulation of weeds and detritus near the feed-pump of the experimental ponds. The series of pump failures that ensued was due mainly to repeated clogging by weeds and detritus contained in the factory wastes. These pumping problems made it impossible to maintain continuous pumping in the modified system.

Inasmuch as waste input control had been a recurring problem, and inasmuch as it apparently became an insurmountable problem under the budget and conditions existing in the fall of 1968, it was decided by the foundation that the experimental Program should be abbreviated for lack of the possibility of controlling the volume of waste input. Despite the fact that the last experiments of 1968 involving the anaerobic-algae pond in series were subjected to extremely close supervision and control, no steady-state could be obtained. In retrospect after viewing the completed data, one realizes that because of load variation, hopes for a high degree of control were unrealistic. In fact, because of drastic changes in waste strength, no steady-state could have been attained regardless of flow control, nor can one expect a true steady-state to ever be maintained on the wastes of a beet sugar factory.

OBSERVATIONS AND ANALYSES

In addition to measuring and maintaining records of pond depth, detention period, recirculation, and mixing, the studies also included measurement of air and water temperatures and light energy input; as well as analyses to determine BOD, COD, total and volatile suspended and dissolved solids, nitrogen, phosphorus, magnesium, calcium, sulfate, and sulfide, algae and other organisms, and algae-packed volume. Counts were made of coliform and fecal streptococci in the influent and at various stages in the system during the previously reported runs in which the MPN dilution method was followed in estimating the concentration of both groups. These results were presented previously (2) and were not repeated in the later series.

SAMPLING TECHNIQUES

Because of its variability, the waste flume water entering the anaerobic pond was composited for analysis. A gravity sampling line was installed to collect waste as it passed through the influent parshall flume where volume was measured. The collected waste was conducted through the line into a nearby refrigerated sample bottle located in a refrigerator. The sample line passed through a solenoid valve that was normally closed. By means of an interval timer, the solenoid valve was opened each hour, permitting about 1 quart of waste to flow to the sample bottle. The contents of this bottle were designated as "influent" and analyzed each day as typical of the influent waste to the anaerobic pond.

During operation the anaerobic pond overflowed through a control and metering weir either to the facultative pond or to the algae pond, depending on the mode of operation. Because of its long detention period (10 to 40 days) and larger volume, the effluent from the anaerobic pond did not vary rapidly in the quality from day to day. A grab sample of the water passing over the weir was collected daily at 9 A.M. and the contents of this sample was designated as "anaerobic" and analyzed each day as typical of the effluent from the anaerobic pond.

During operation the facultative ponds overflowed through a control and metering weir into the algae pond. Because of its long detention period (10 to 40 days), the facultative pond did not vary rapidly in quality. Accordingly, a grab sample of the water passing over the weir was collected daily when the pond was in operation and this grab sample was designated as "facultative" and analyzed each day as typical of the effluent from the facultative pond.

During the operation of the algae pond, it overflowed into an effluent sump and into a recirculation sump. Because of its long detention period (5 to 20 days) and large volume, the effluent from the algae pond did not vary rapidly in quality from day to day. It did, however, vary with time of day, particularly with respect to pH, temperature and dissolved oxygen. However, a 9 A.M. grab sample was collected daily and the contents labeled "algae". This was analyzed each day as typical of the effluent from the algae pond. Diurnal changes in the algae pond were detected when desired by 24 hour sampling or by taking 3 P.M. samples in the pond as well as the regular 9 A.M. samples.

Inasmuch as the effluent sump and the recirculating sump were located near one another in the algae pond, the sample labeled "algae" was also assumed to be typical of the recirculant.

When, due to flow interruptions the ponds were not overflowing, grab samples were taken from each pond near the outlet where the overlfow samples would have normally been taken.

Although 24-hour compositing of all samples from each portion of the system would have been desireable, budgetary limitations and operational difficulties made such a sampling program impossible. However, influent composite sampling was the major need because influent variation was inherently far greater than that of the effluents from the various ponds.

Routine analyses were made according to techniques given in Volume 12 of Standard Methods for Examination of Water and Wastewater (3), with the exceptions described below. Gas production was studied with Bronson gas collectors (shown in Figure 4). Data on methane fermentation were limited to the final series both because a clearcut methane fermentation did not become established in the ponds, and because gas emission measurements were interrupted by water condensation in the transmission lines from the Bronson collectors to the gas meters in all but the final runs.

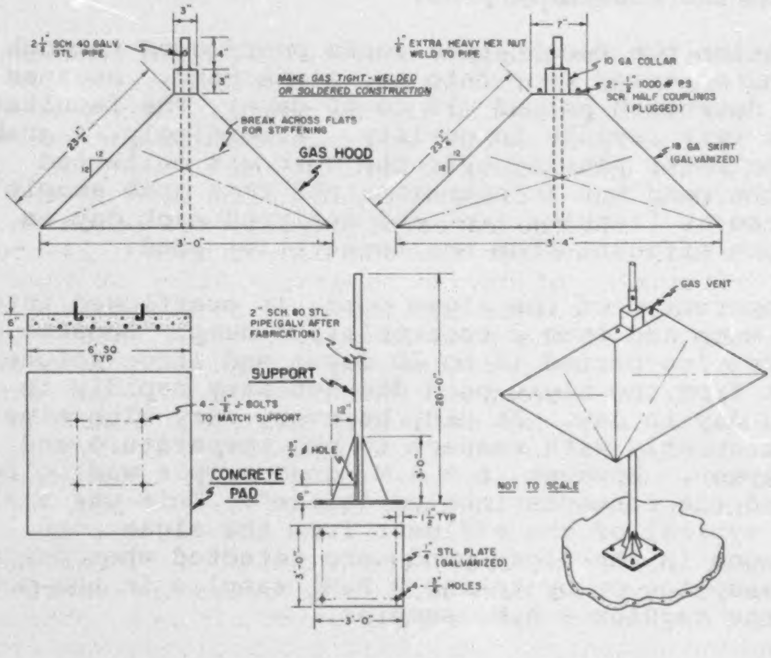
3"
2 1/2" SCH 40 GALV STL PIPE
4"
3"
MAKE GAS TIGHT-WELDED OR SOLDERED CONSTRUCTION
BREAK ACROSS FLATS FOR STIFFENING
GAS HOOD
23 1/2"
12
12
3'-0"
7"
1/2" EXTRA HEAVY HEX NUT WELD TO PIPE
10 GA COLLAR
2 - 1/2" 1000 # PS SCR HALF COUPLINGS (PLUGGED)
18 GA SKIRT (GALVANIZED)
23 1/2"
12
18
3'-4"
6"
6' SQ TYP
4 - 1/2" J-BOLTS TO MATCH SUPPORT
CONCRETE PAD
2" SCH 80 STL PIPE (GALV AFTER FABRICATION)
SUPPORT
12"
5/8" ⌀ HOLE
20'-0"
3'-0"
6"
1 1/2" TYP
1/4" STL PLATE (GALVANIZED)
4 - 1/2" HOLES
3'-0"
3'-0"
GAS VENT
NOT TO SCALE

FIGURE 4. BRONSON GAS COLLECTOR

Instead of using the standard method test for odor in drinking water, a method was developed for expressing odor, described as the organoleptic test. This was done by establishing six arbitrarily designated characteristic odors: 1 - none; 2 - beets; 3 - other; 4 - cow dung; 5 - H_2S; and 6 - foul. Also, six intensities were arbitrarily established: 1 - being a very low intensity and 6 - being a high intensity. The arbitrarily assigned numbers were multiplied together to give an "odor product". The lowest odor product possible is 1 and the highest, 36. A sample which smelled like H_2S and was moderately intense would have an odor product of 5 x 3 or 15. A strong beet smell would have a product of 2 x 6 or 12 and so on.

During November, 1968, because of apparent deficiencies in certain nutrients in the main factory waste, a special bioassay was made to determine whether or not certain nutrients such as potassium phosphate, ammonia phosphate, ammonium nitrate, sodium nitrate, phosphoric acid (20%), and 15-8-4 commercial fertilizer would be of any benefit to algae growth and photosynthetic oxygenation in the system. The bioassay technique used closely followed that for Provisional Algal Assay Procedures recommended by the Federal Water Quality Administration (4). Indigenous algae rather than Selenastrum were used for the assay organism, and hand mixing of the cultures was employed.

During the course of the studies, several 24-hour studies were conducted to obtain information on the diurnal rates of oxidation and photosynthesis in the ponds. Twenty-four-hour studies of dissolved oxygen and temperature are extremely valuable in systems undergoing oxidation and photosynthetic oxygenation because the data permits an evaluation of the rates of oxygen-use and the rates of oxygen production in the system. One requirement for the success of such a 24-hour study is the attainment of oxygen supersaturation at some point in time. At the points in time that the dissolved oxygen concentration of the pond is equal to the saturation concentration for that temperature, no exchange of molecular oxygen occurs with the atmosphere and consequently the observed rates are independent of gas exchange, and are a function solely of the difference between the rates of photosynthetic oxygen production and respiration. In spite of several efforts, supersaturation was reached in only one 24-hour study.

During the early summer of 1968, the algae pond system was drained and modifications were made to prevent the short-circuiting of flow under the baffles which had been observed during the spring campaign. This short-circuiting was estimated to have reduced the portion of the algae that was actually mixed to less than one-half the total area. Inasmuch as short-circuiting beneath the baffles caused this problem, earth was piled on either side of the baffles to about 12" above the base. It was found later that even this drastic measure did not entirely prevent short-circuiting, but it did reduce the short-circuiting considerably.

A schematic diagram of the system used for the final runs is shown in Figure 5.

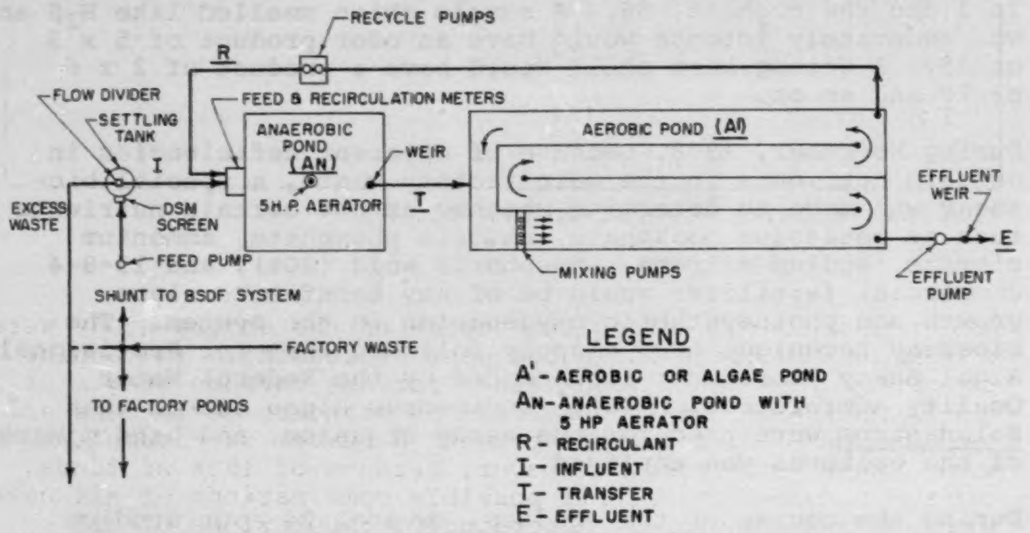
RECYCLE PUMPS
R
FLOW DIVIDER
SETTLING TANK
FEED & RECIRCULATION METERS
ANAEROBIC POND (AN)
WEIR
AEROBIC POND (A')
I
EXCESS WASTE
DSM SCREEN
5 H.P. AERATOR
T
EFFLUENT WEIR
E
FEED PUMP
MIXING PUMPS
EFFLUENT PUMP
SHUNT TO BSDF SYSTEM
FACTORY WASTE
TO FACTORY PONDS
LEGEND
A' - AEROBIC OR ALGAE POND
AN - ANAEROBIC POND WITH 5 HP AERATOR
R - RECIRCULANT
I - INFLUENT
T - TRANSFER
E - EFFLUENT

FIGURE 5. SCHEMATIC DIAGRAM OF SYSTEM AS APPLIED IN AERATED ANAEROBIC PLUS MIXED ALGAE POND SERIES

The final run of the series was initiated on July 27, 1968, and terminated on December 17, 1968. Desired operational procedures for the final run were a feed rate of 150 gallons per minute and a recirculation rate of 150 gallons per minute. This rate was chosen on the theory that it would force more of the BOD load to be conveyed through the anaerobic pond and into the photosynthetic or algae pond. Nominal depths for the ponds were to be 14' for the anaerobic pond; while the algae pond was to have a variable depth beginning at 42" and adjusted downward as light diminished.

Operating depths for the ponds during this period are shown in Table 1. Every effort was expended to maintain the feed at a constant rate but as noted previously, pump failures, clogging, and extreme changes in waste concentration caused both the hydraulic and organic feed rate to vary. In spite of these difficulties, data collection was persistent and complete, and the data were thoroughly processed to evaluate major parameters.

TABLE 1

Operating Depths for Ponds During July - Dec. 1968 Runs

Period	Nominal Operating Depth ft.*	
	Anaerobic	Algal Pond
July - Aug.	14	3.5
Sept. - Oct.	14	2.5
Nov. - Dec.	14	2.0

*Depths varied ± several inches during the course of each run.

All data gathered during the course of the entire study were stored on IBM cards for subsequent processing. In machine processing the data, mean values for the various stages of the system were obtained as well as standard deviations and variability. Correlations between a number of parameters were sought and found. However, because of lack of funds, complete processing of all possible combinations of all data has not been possible. Accordingly, tabulations of all of the day-to-day data from the final run are included in an appendix to this report so that they can be further processed by any who are interested and have the funds to do so.

SECTION V

RESULTS

GENERAL WASTE CHARACTERISTICS

One factor of considerable interest is that of the general characteristics of beet sugar flume water. A compilation of the mean values of all determinations made for the Holly sugar waste during the 1965 to 1968 study is presented in Table 2. Standard deviations for these values were very large. As shown for the solids data in Table 2, the variance, σ/M, in some cases exceeded 1000%. Because of the great differences, not all variances were computed, and hence the blanks in Table 2.

PHOTOSYNTHESIS AND RESPIRATION

As noted previously, only one of the 24-hour studies undertaken yielded data which could be used successfully in determination of respiration and photosynthetic rates. The pond involved was the algae pond at a time when its nominal loading was about 60 lbs per acre per day. The run was made before the baffles and mixing system were installed in the algae pond.

Results of that run are plotted in Figure 6. From the figure it may be observed that the exchange independent rate of respiration was 0.467 mg O_2 per liter per hour, and the mean photosynthetic rate at the surface netted 1.16 mg per liter per hour. The gross surface photosynthetic rate including respiration was 1.62 mg per liter per hour. From these data the rate of oxygen-use by the pond was 86 lbs per acre per day. The net surface photosynthetic oxygen production was 214 lbs per acre per day, and the gross surface rate, 300 lbs per acre per day. Inasmuch as the rate decays logrithmically with depth, the average rate with depth would be about one-third the surface rate or about 100 lbs per acre per day. The apparent photosynthetic efficiency of the algae pond, assuming a sunlight energy input of 200 cal/cm^2 per day, was then about 2.3%. This rate of oxygenation is slightly greater than the rate of deaeration based on the respiration rate of the system. On the other hand, the respiration rate of the system must have been more than satisfied because the oxygen level was continuously near saturation. Inasmuch as the system was supersaturated during daylight hours and barely fell below saturation at night, there must have been a net export of O_2 from the system.

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TABLE 2

Mean Values for Certain Analytical Parameters of Holly-Tracy Flume Water - 1965 - 1968

(Following 16 mesh DSM screening and 1.5 hr. sedimentation)

Parameter	Units	Value	Variance
Total Nitrogen (N)	mg/l	16.4	--
Ammonia (N)	"	6.3	--
Nitrate (N)	"	2.6	--
Chlorides	"	400 *	--
Sulfate	"	210.0	--
Alkalinity ($CaCO_3$)	"	538.0***	--
Sulfide	"	0.68	--
Phosphate (P)	"	3.4	--
Calcium	"	178.0	--
Magnesium	"	66.0	--
Sodium	"	222.0**	--
Potassium	"	88.0**	--
BOD (unfilt.)	"	930.0	--
COD (unfilt.)	"	1601.0	--
COD (filt.)	"	1195.0	--
Suspended Solids	"	1015	11269
Suspended Volatile	"	360	7140
Suspended Ash	"	655	6348
Dissolved Solids	"	2209	6016
Dissolved Volatile	"	1139	2764
Dissolved Ash	"	1070	7754
Total Solids	"	3224	14979
Total Volatile	"	1499	4456
Total Ash	"	1725	8328
Sugar	"	1.25	0.25
Dissolved Oxygen	"	0.0	
Physical factors			
pH		7.06	1.8
Light Penetration	cm	45.6	17.8
Specific Conductance μ mhos	cm	300	299

*Based on specific conductivity
**Single values
***By difference

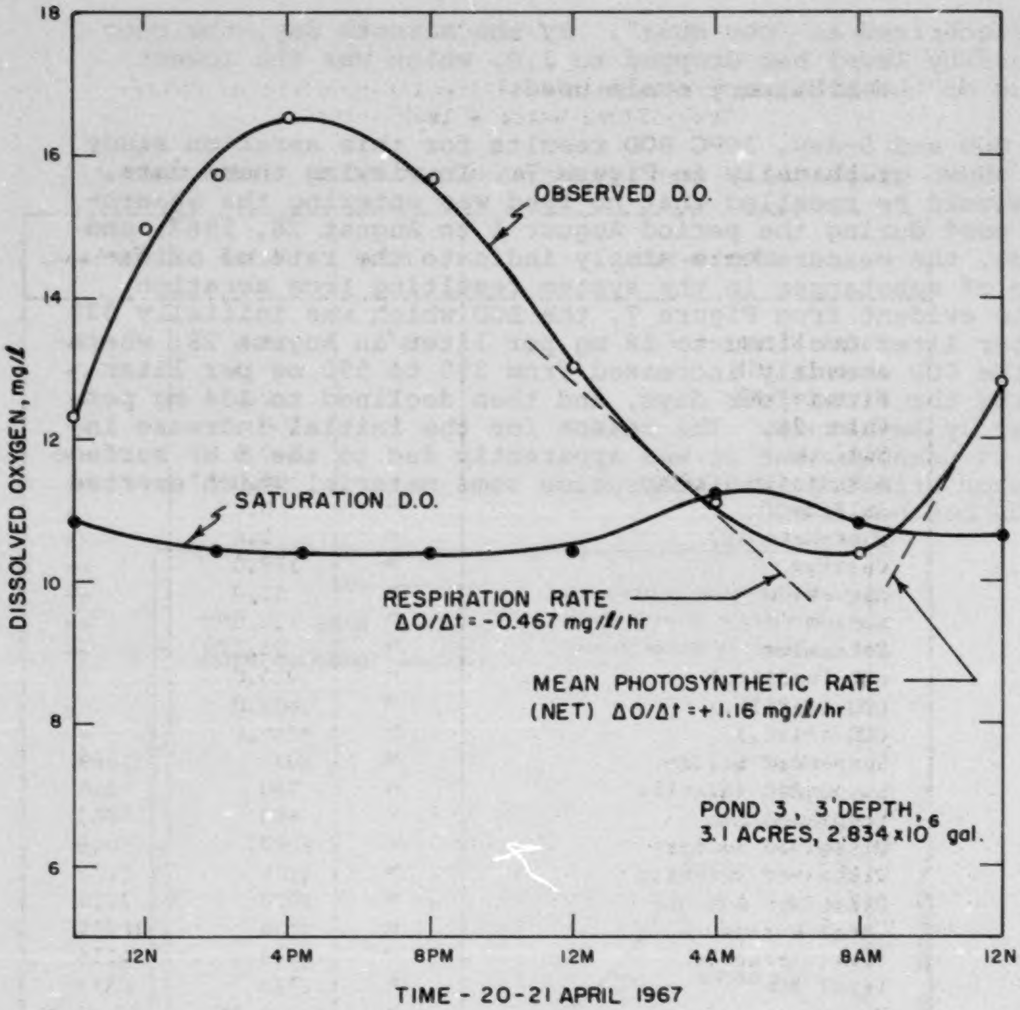

FIGURE 6. DISSOLVED OXYGEN VS TIME OF DAY

FLOATING AERATOR STUDY

A five-horsepower floating surface aerator was installed in the system on July 31, 1967 and was positioned in the anaerobic pond near the center as shown in Figure 1. During the prior spring campaign, the anaerobic pond had been heavily loaded; and following several weeks without feed, the BOD remained at 325 mg per liter. Prior to the study, the odor intensity level of the anaerobic pond was at the 10 to 12 level, and was characterized by a foul hydrogen sulfide stench that had barely improved after standing several weeks. After three days of aeration with the new aerator, the odor intensity dropped to a level of 4. The odor quality became that characterized as "cow dung". By the seventh day, the odor intensity level had dropped to 1.0, which was the lowest value on the arbitrary scale used.

The COD and 5-day, 20°C BOD results for this aeration study are shown graphically in Figure 7. In viewing these data, it should be recalled that no feed was entering the anaerobic pond during the period August 1 to August 28, 1967; and hence, the measurements simply indicate the rate of oxidation of substances in the system resulting from aeration. As is evident from Figure 7, the BOD which was initially 330 mg per liter declined to 18 mg per liter on August 28; whereas the COD steadily increased from 390 to 590 mg per liter during the first four days, and then declined to 134 mg per liter by August 28. The reason for the initial increase in COD is unknown, but it was apparently due to the 5 HP surface aerator bringing into suspension some material which exerted a COD but not a BOD.

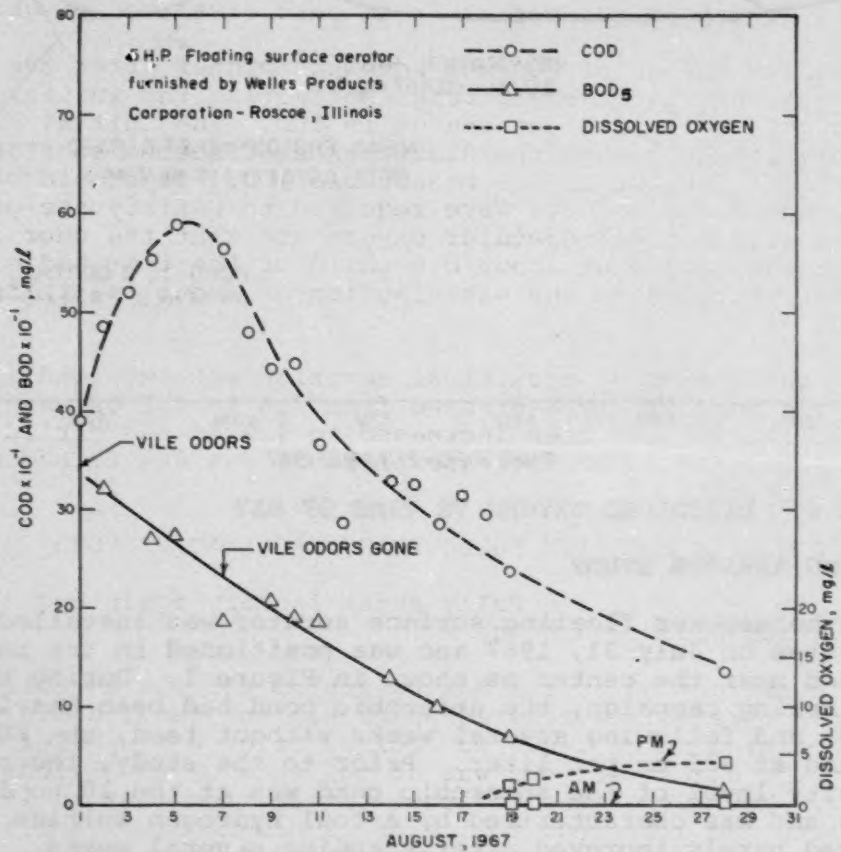

FIGURE 7. CHANGE IN COD, BOD AND D.O. IN ANAEROBIC POND DURING SUSTAINED AERATION WITH 5 H.P. FLOATING SURFACE AERATOR

During the period August 1 to August 16, no dissolved oxygen was detected in the system. After August 19, dissolved oxygen began to appear in the water during the afternoons, although it would be at zero concentration in the mornings. This indicates that after August 19 photosynthetic activity was beginning to replenish oxygen in the system even while oxygen was being introduced by the aerators.

During the period August 1 to August 16, the BOD decreased from 335 mg per liter to 100 mg per liter. Thus, in 15 days, the total reduction was 235 mg per liter. Inasmuch as during this period the volume of the anaerobic pond was about 2.5 million gallons, the rate of oxidation must have been 235 x 2.5 x 8.34 = 4,900 lbs of BOD or 327 lbs per day. Assuming that during this period natural reaeration contributed 20 lbs per day (the surface area being 1 acre), the aerator must have contributed 307 lbs per day or 2.54 lbs per HP hr. This rate is precisely that published by the manufacturer (5), namely, 3.2 lbs of 0_2 per kw hr at zero dissolved oxygen.

The rate of change of COD was somewhat higher after the first five days, but the overall rate, neglecting the initial "hump", corresponds well with the change in BOD. The initial hump probably resulted from the disturbance of bottom substances which had a COD but little measurable BOD. It should be noted that about 20 days were required to satisfy the pond BOD and attain free molecular oxygen and that the odor level had dropped to 1 when about one-third of the time had elapsed. This corresponded to the satisfaction of about one-third of the BOD.

During the period of mechanical aeration without loading, the pH in the pond slowly decreased from 7.6 to 7.1 between August 1 to August 10, and then increased to 7.9 in the period August 11 to August 18. The increase probably was due to photosynthetic activity.

ANAEROBIC WITH AERATION FOLLOWED BY FACULTATIVE POND

On August 28, 1967, the Holly sugar factory again began to operate and produce wastes.

While construction of the mixing system for the aerobic pond was in progress, the aerated anaerobic and facultative ponds were operated in series. No recirculation was applied. Loading to the anaerobic pond was at the rate of 25 gallons per minute. The BOD of the influent ranged from 1308 to 1639 ppm. The waste had a strong, foul odor, a brown color, and a nitrogen content of 64 mg per liter--indicating the intrusion of Steffen waste into the flume water. The effluent BOD from the anaerobic pond began to increase, and rose from 18 to 53 mg per liter within a week. It reached 129 mg per liter by the end of the 25-gpm run. During the same time, the COD rose from 134 to 228 mg per liter. Odor at first increased and then declined. At the feed rate of 25 gallons per minute, the organic load entering the anaerobic pond was between 400 and 500 lbs per acre per day, exceeding by 75 to 175 lbs the daily aeration capacity of the 5 horsepower floating aerator. Frequent interruptions in flow due to influent pumping failures at first permitted the persistence of a small residual of dissolved oxygen in the surface layers of the anaerobic pond, and kept the odor intensity level down to about 5. When the loading rate was increased to 50 gpm, all dissolved oxygen disappeared from the system.

Key results of the 1967 fall runs 13 through 18 are summarized in Table 3. According to the table, loadings varied from 900 to 0 lbs per acre per day. Generally speaking, most of the BOD was removed in the anaerobic pond.

Because of the high removals in the anaerobic pond, loadings to the facultative pond were always less than 180 lbs per day. Effluents from the facultative pond varied from 45 to 140 mg per liter BOD, with little apparent relationship to applied BOD. During this period, the facultative pond contained a rich culture of *Oscillatoria limosa* which remained in suspension, and apparently in some cases retained nitrogen to the extent that nitrogen concentrations in the facultative pond were higher than those in the anaerobic pond. *O. limosa* concentration in the facultative pond reached concentrations approaching 100 mg per liter. Nitrogen concentrations in the anaerobic pond were always less than those in the influent--a fact which confirms the high nitrogen removals in the anaerobic pond reported in the Third Progress Report (1).

ANAEROBIC WITH AERATION FOLLOWED BY ALGAE POND

Heavy rains from November through March of 1967-68 made pilot plant operations impossible. The spring campaign at Holly was initiated on March 28 and extended to May 27, 1968. The anaerobic pond with aeration was operated in series with the aerobic algae pond with mixing. The facultative pond was bypassed. During the 60-day period, there were 10 days of down time due to weather, and 44 days of down time due to feed pump failures. Efforts were made to operate the system with a feed rate of 100 gallons per minute, but again day-by-day problems with pump clogging continuously interrupted the flow. Various modifications were made in the waste transfer and feed system, the major one being an automatic backflush cleaning cycle installed on the feed pumps system. However, due to large amounts of vegetation in the main factory waste, this

TABLE 3

RESULTS

1967 Aerated Anaerobic Pond Plus Facultative Pond With No Recirculation

Pond	Run	Flow gal/min	Load lbs day	BOD mg/1	COD mg/1	Vol Sol mg/1	Total N mg/1	Odor Product
Inf	13	25	--	1500	1776	1450	22	12
An	"		450	129	321	491	15.2	5
Fac	"		39	79	370	584	20.5	3
Inf	14	50	--	1490	1814	1172	38.9	16
An	"		900	101	276	401	17.7	9
Fac	"		61	77	493	625	24.3	3
Inf	15	75	--	983	1532	781	23.2	6
An	"		900	200	402	412	20.4	10
Fac	"		180	113	512	631	23.6	3
Inf	16	0	--	726	--	454	--	6
An	"		--	314	452	454	15.7	10
Fac	"		--	140	550	508	21.7	3
Inf	17	50	--	1202	1455	1065	35.0	4
An	"		730	184	371	470	21.4	14
Fac	"		110	64	408	563	20.7	3
Inf	18	50	--	665	1220	882	25.8	--
An	"		--	142	402	495	25.2	--
Fac	"		--	47	426	583	21.6	--

installation only slightly ameliorated the continual clogging. Since recirculation rates of 100 gallons per minute (nominal) were maintained throughout the period, a considerable amount of the loading to the anaerobic pond was transferred forward into the algae pond. In spite of flow interruptions, by April 11, when a major pump failure occurred, the anaerobic pond had begun to develop a sulfide odor and contained a measured dissolved sulfide level of 0.5 mg per liter. During this campaign, there was intermittent occurrence of daphnia in the algae pond. The daphnia grazed the algae excessively. As a result of the loss of algae through the grazing activity of the daphnia, the dissolved oxygen dropped to near zero on several occasions. When the major feed pump failure occurred, a second feed pump was rushed into operation, but was only installed a few days before factory shut down for the summer break. Because of the sporadic nature of this series and frequent interruptions due to weather and pump failures, the data from this series of runs were not processed.

The final series of tests were conducted during the summer and fall of 1968 (July 27 to December 18, 1968). As noted previously, a great difficulty was encountered in maintaining flow rates. Nevertheless, the experiments were conducted as nearly as possible according to schedule and with detailed recording of all factors. The results of this series of runs are presented in more detail than were the others in an effort to obtain maximum value from the study.

In order to simplify presentation of the data, daily values for all parameters are tabulated in the Appendices as a function of day and month. In some cases, seasonal variations were predominant; but in most cases, day-to-day variations in the data were large. These variations probably resulted mainly from genuine variations in the materials sampled rather than from variations in the analytical techniques, although the latter variations no doubt also occurred. Machine processing of the data simply indicated the enormity of the variations encountered and did little to clarify any basic relationships. A number of strong relationships are, however, quite evident from the data. Hence, the data to be used in showing these relationships were reprocessed simply by taking arithmetic averages of all data month by month. Although this was a laborous and time-consuming process, the results indicate that it was worthwhile. These arithmetic averages are to be found at the bottom of each column of daily values in the Appendices. A statistical treatment of the data was not made because its chronological arrangement would have merely brought out variances due to weather and changing waste characteristics which are quite obvious in the daily data. In addition to being presented in the Appendices, groups of arithmetic means which may lead to conclusions are also presented in tabular form in the body of the report and are plotted in figures where greater clarity is required for discussion.

ENVIRONMENTAL CONDITIONS - Results of daily measurements of solar energy waste and pond temperatures, and maximum and minimum air temperatures are tabulated in Appendices A-1, A-2 and A-3. Monthly mean values for each of these parameters are plotted in Figure 8.

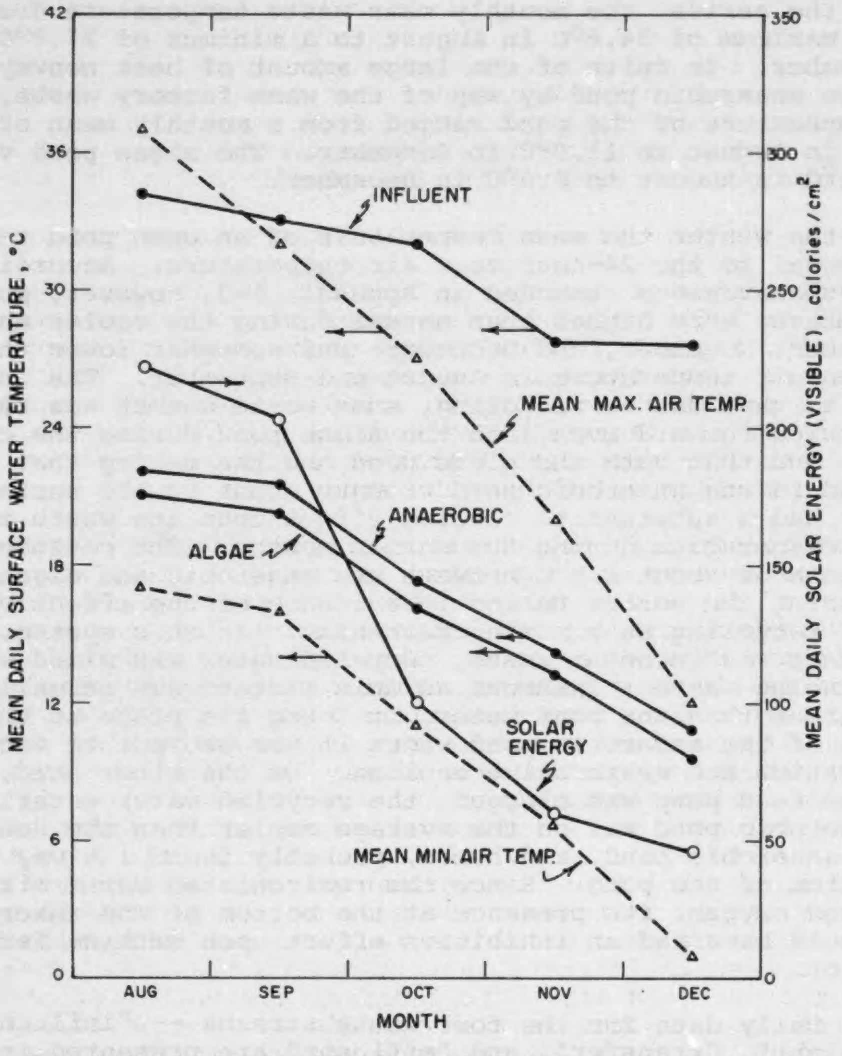

FIGURE 8. MEAN VISIBLE SOLAR ENERGY AND SURFACE WATER TEMPERATURE, MAXIMUM AND MINIMUM AIR TEMPERATURE AS A FUNCTION OF MONTH

As indicated in the figure, visible solar energy varied from a mean of about 225 gm cal per cm^2 in August to a mean of about 50 gm calories per cm^2 in December.

Mean monthly maximum air temperature declined from 37°C in August to 12°C in December, and the mean monthly minimum air temperature dropped from 17°C in August to 1°C in December.

During the series, the monthly mean waste temperature dropped from a maximum of 34.4°C in August to a minimum of 27.7°C in December. In spite of the large amount of heat conveyed into the anaerobic pond by way of the warm factory waste, the temperature of the pond varied from a monthly mean of 22.2°C in August to 11.0°C in December. The algae pond varied from 21°C in August to 9.6°C in December.

During the winter the mean temperature of an open pond tends to be equal to the 24-hour mean air temperature. According to the observations recorded in Appendix A-3, however, pond temperatures were higher than normal during the cooler months of October, November, and December; and somewhat lower than the mean air temperature in August and September. The indication is that due to recycling, some waste warmth was retained and carried forward even into the algae pond during the cold months; and that both the algae pond and the mixing that occurred in the anaerobic pond brought about by the surface aerator had a substantial cooling effect upon the waste mass due to evaporation during the warmer months. The constant difference of about 1.5°C between the anaerobic and algae pond during the entire period is evidence of the effectiveness of recycling as a mixing mechanism. In this system, when there was incoming waste, recycled water was mixed with the incoming waste. Inasmuch as this mixture was normally much warmer than the pond water, it found its place at the surface of the anaerobic pond where it was subject to mechanical aeration and evaporative cooling. On the other hand, when the feed pump was clogged, the recycled water entering the anaerobic pond was on the average cooler than the contents of the anaerobic pond, and hence, probably found its way to the bottom of the pond. Since the recirculated water often contained oxygen, its presence at the bottom of the anaerobic pond would have had an inhibitive effect upon methane fermentation.

FLOWS - Daily data for the four waste streams -- "influent", "recirculant", "transfer", and "effluent" are presented in detail in Appendices B-1, B-2 and B-3. The meaning of the term I, influent, R, recirculant, T, transfer, and E, effluent as applied to the waste streams can be visualized through reference to Figure 5 in which each stream is indicated by an arrow labeled with the appropriate letter.

As noted previously and as is evident from the data, the steady-state conditions were never approached in the system. Flow interruptions due to pump clogging and pump failure frequently occurred for reasons previously described.

Variability in the feed stream plus variations in percolation and evaporation led to loss of volume, so that the volume of effluent should have theoretically always been less than that of the influent. However, as indicated in the summary table for flows, cf. Table 4, mean effluent flow in September exceeded the influent flow. This reflected the fact that the algae pond initially was to be filled to about 42". During August it became evident that this depth was excessive and a depth of 30" was determined to be more favorable. Inasmuch as the pond already had been filled to a depth of about 41", some 600,000 gallons of excess water had to be discharged. During November, another apparent anomaly occurred in which effluent exceeded influent. In this case, interruptions in the influent flow reduced the mean influent to 17 gpm while rainfall plus a second depth adjustment of the algae pond to a nominal depth of 24" increased the mean effluent to 33 gallons per minute. Nominal operational depths for the ponds during the various periods were shown previously in Table 1. The longest sustained run was made during October, a month in which evaporation is normally equal to precipitation. Because evaporation equalled precipitation, the difference of 52 gallons per minute between influent and effluent was due mainly to percolation. This difference amounted to about 75,000 gallons per day or 19,000 gallons per acre per day over the ponding area. This rate is somewhat higher than is generally reported for ponds in the Tracy area and may reflect errors in flow measurement.

LOADINGS - Because of wide variations in flows and BOD values, only crude materials balances could be established for the system. Measures of unfiltered COD, filtered COD, and unfiltered BOD were made frequently on the influent and on the effluent from the anaerobic and algae ponds. All of these data are tabulated in Appendices C-1, C-2 and C-3, and the monthly mean values are summarized in Table 5. According to Table 5, the unfiltered COD of the factory waste increased from a mean value of 1482 mg per liter in July to a mean value of 2380 mg per liter in December. The corresponding filtered COD values increased from a mean of 603 mg per liter in July to 1969 mg per liter in December. Thus, the increase in COD during the course of the campaign apparently was due to the presence of soluble substances. The unfiltered BOD

TABLE 4

Summary of Mean Monthly Flow Values for Influent Recycle, Transfer and Effluent Waste Streams

Month	Stream	Monthly Mean Flows	
		Gal/Min	Gal/day x 10³
Jul	Influent[1]	61	88.0
	Recycle[1]	148	216
	Transfer[1]	--	--
	Effluent[1]	--	--
Aug	I	105	152
	R	148	215
	I	100	144
	E	22	32.0
Sept	I	75	108
	R	148	215
	T	183	264
	E	90[2]	130[2]
Oct	I	128	185
	R	148	215
	T	195	282
	E	76	110
Nov	I	17	24.5
	R	23	33.1
	T	26	37.4
	E	33[3]	47.5[3]
Dec	I	82	118
	R	82	118
	T	113	163
	E	36	52.0

[1] For significance of terminology see Figure 5

[2] Effluent exceeded influent due to draw down of algal pond to reduce operating depth from 40" to 30"

[3] Effluent exceeded influent because of rainfall, depth reduction and reduced influent

TABLE 5

Summary of Monthly Mean COD and BOD Values as a Function of Pond and Month

Month	Samp	Unfilt COD mg/l	Filt COD mg/l	$\frac{\text{COD}}{\text{BOD}}$ Unfilt	Unfiltered BOD			Filt BOD mg/l
					5-day 20°C mg/l	Ult 20°C mg/l	Ult 20°C lbs/1000 gal	
Jul[1]	Inf	1482	603	1.85	803	1180	9.85	
	An	261	119	2.54	103	151	1.61	
	Al	150	142	3.00	50	73	0.61	
Aug	Inf	1450	961	1.48	985	1440	12.00	
	An	389	217	2.11	184	269	2.24	
	Al	314	112	3.20	98	143	1.19	13[2]
Sept	Inf	1559	1128	1.81	863	1260	10.50	
	An	630	144	3.78	167	245	2.04	
	Al	544	116	4.17	130	191	1.59	10[3]
Oct	Inf	1570	1180	2.50	625	915	7.60	
	An	750	137	8.25	91	133	1.11	
	Al	656	104	11.90	56	82	0.68	
Nov	Inf	1960	1541	2.01	971	1420	11.80	
	An	715	209	6.0	119	174	1.45	
	Al	610	150	11.0	55	81	0.67	
Dec	Inf	2380	1969	2.47	963	1410	11.75	
	An	759	165	9.80	78	114	0.95	
	Al	579	130	10.00	58	85	0.70	

[1] Values for July are based on single or duplicate tests only
[2] Single sample
[3] Mean of four weekly samples

did not parallel the COD, but rather decreased in October. This decline raises the definite possibility of the presence of toxic or refractory substances in the pond or waste during October, November, and December, inasmuch as the normal COD-BOD ratio for raw waste has been found to be about 1.67 (1), and for completely treated waste, on the order of 4. These ratios do not account for changes in solubility of organics, for their refractory characteristics, or for their toxicity. A further description of the results of the BOD and COD studies will be presented in a later section. For the present, only loading and overall system performance are given.

Unfiltered BOD values were used together with flow data to compute loadings. The unfiltered 5-day, $20^{\circ}C$ BOD values are plotted in Figure 9. Monthly mean loadings and performance data based upon monthly mean flows and BOD values (converted to ultimate BOD) for the anaerobic-algae pond in series are listed in Table 6. A study of the table shows that with the exception of September and November, when depth adjustments were made, the system attained a 95% or better overall ultimate BOD removal, and that even though a large amount of waste water was discharged in September, an overall removal of 84% was attained. The input-output balance for the two ponds shows that little or no net removal was attained in the algae pond in that the amount varied from -3 to 30 lbs per acre per day. The major removals in the system were attained in the anaerobic pond. The algae pond did, however, convert some of the BOD to a more removable form, as is evidenced by the fact that the filtered BOD from the algae pond was as low as 10 mg per liter. Had complete separation of the solid fraction from the algae pond effluent been a routine procedure, the overall BOD removal of the system referred to as soluble BOD would have been in excess of 99%. It should be noted that one of the major factors contributing to poor overall BOD removals in the algae pond in terms of unfiltered algae pond effluent was the fact that it was continuously mixed. Another factor was the presence of predators in the pond which occasionally destroyed the algae crop almost entirely, and thereby reduced the pond dissolved oxygen to zero. Another contributing factor was that inasmuch as the anaerobic pond was so efficient, the applied loading to the algae pond was low, the opportunity for removal was also low.

In general, BOD removal in the anaerobic pond was found to be directly proportional to loading at all loading rates up to 2,000 lbs per day. The concentration of ultimate BOD moving into the algae pond was greater than 245 mg per liter in August and September and over 114 mg per liter in October, November, and December. BOD values of this magnitude are not normally acceptable in the aquatic environment, hence, although the anaerobic pond accepted high loadings and accomplished high removals, it often was malodorous and discharged an effluent having a high BOD. Thus, even though the algae pond was apparently inefficient, it was an essential part of the system because it brought about a decrease in the final BOD of the overall system to a level which would be acceptable in the aquatic environment, particularly if the algae were removed.

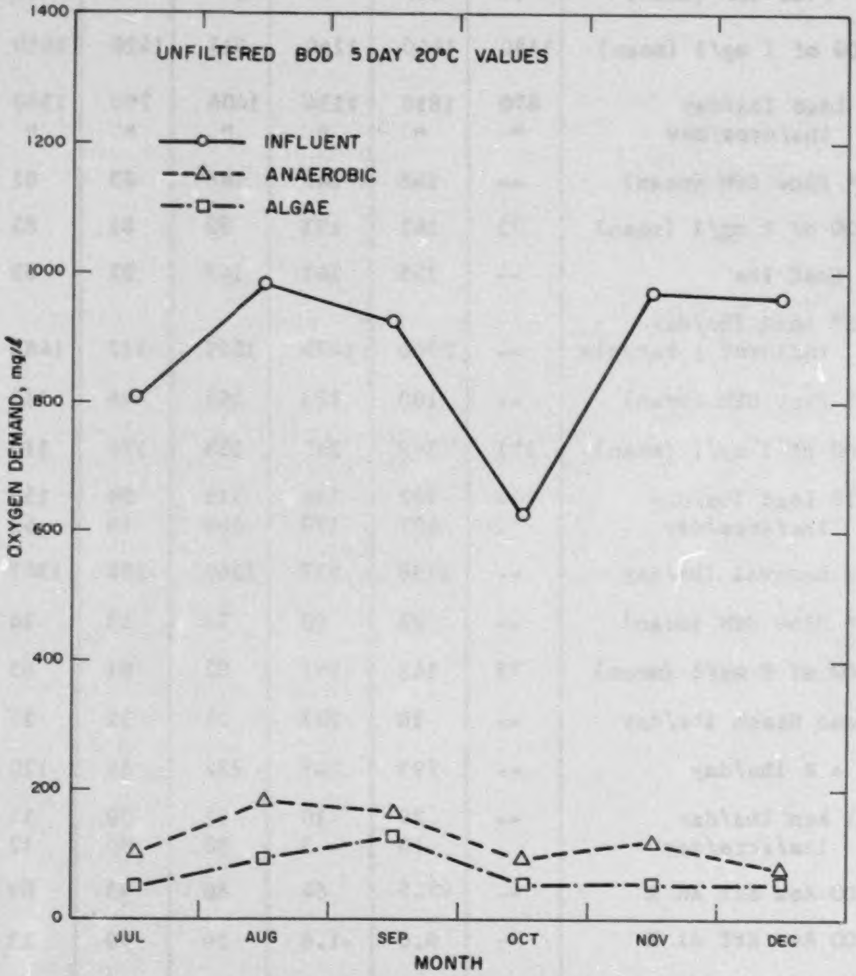

FIGURE 9. MONTHLY MEAN VALUES FOR UNFILTERED BOD AS A FUNCTION OF POND AND MONTH

TABLE 6

Monthly Mean Flows BOD Values and Performance Data for Anaerobic-Algae Pond in Series

Month 1967	Jul	Aug	Sep	Oct	Nov	Dec
I* Flow GPM (mean)	88	105	75	128	17	82
BOD of I mg/l (mean)	1180	1440	1260	915	1420	1410
I Load lbs/day lbs/acre/day	870 "	1810 "	1134 "	1406 "	290 "	1380 "
R* Flow GPM (mean)	--	148	148	148	23	82
BOD of R mg/l (mean)	73	142	191	82	81	85
R Load lbs	--	255	341	147	22	83
An* Load lbs/day influent + recycle	--	2060	1475	1553	312	1463
T* Flow GPM (mean)	--	100	183	195	26	113
BOD of T mg/l (mean)	151	268	245	133	176	114
Al* Load lbs/day lbs/acre/day	--	322 107	538 179	313 104	54 18	156 52
An Removal lbs/day	--	1738	937	1240	258	1307
E* Flow GPM (mean)	--	22	90	76	33	36
BOD of E mg/l (mean)	73	142	191	82	81	85
Load Disch lbs/day	--	38	207	75	32	37
E + R lbs/day	--	293	548	222	54	120
Al Rem lbs/day lbs/acre/day	--	29 10	-10 - 3	91 30	00 00	36 12
BOD Rem Eff An %	--	95.5	64	80	83	89
BOD Rem Eff Al %	--	9.0	-1.8	29	00	23
Overall Eff % of BOD Removal		98	84	95	89	98

*Letters identified in Figure 5

N.B. All BOD values are ultimate BOD's, i.e. 5-day BOD/.684

The magnitude of decrease in BOD in the algae pond was from 30 to 126 mg per liter. It apparently also rendered the recirculant more treatable in the sense that additional substantial removals were attained as recirculated waters were again passed through the anaerobic pond.

PHYSICAL CHARACTERISTICS OF LIQUIDS - Physical characteristics of influent and anaerobic and algae pond effluents are tabulated by day and month in Appendix D. Included are pH, (D-1), dissolved oxygen (D-2), volatile and fixed dissolved and suspended solids (D-3, D-4, D-5, D-6), centrifuged volumetric solids (D-7), conductivity (D-8), and light penetration (D-9).

pH: A summary of pH relationships for the period is given in Figure 10. In general, influent pH variations were extremely large, varying from 5.8 to 11.7 throughout the period. The middle value as evidenced by the horizontal line in the vertical bars of Figure 10 was about 8.6 in August, 7.6 in September, 9.1 in October, 8.8 in November, and 8.5 in December. By contrast, the pH in the anaerobic pond varied a maximum of 2.0 units, and in most cases was 1 full unit lower than that of the influent. Its level was 7.55 in August, 7.75 in September, 8.1 in October, 7.7 in November, and 6.5 in December. The low value in December possibly indicates that due to low temperatures, a buildup of volatile acids was occurring in the system at that time. The high value in October perhaps indicates restricted biological oxidation and CO_2 production.

When photosynthetic activity occurs in a pond, the pH usually tends to increase particularly as a function of time of day. This in turn leads to an overall increase in pH throughout a pond system. The degree of increase in pH in the algae pond during August and December was not large; and in fact was found to have decreased in September, October, and November. As will be demonstrated later, a severe rotifer infestation occurred in the ponds during the last-named three months. In spite of the evident decreases in pH from the anaerobic to algae pond, a detailed perusal of the data in Appendix D-1 will show that in many cases there was indeed an increase in pH. Considerable photosynthetic activity also took place in the anaerobic pond, as was shown by the algae concentration of the pond.

Dissolved oxygen is, of course, one of the major indicators of photosynthetic activity and this was measured twice daily in the influent, anaerobic and algae ponds. It was found that free molecular oxygen never was present in the influent, and that the free molecular oxygen in the anaerobic pond was

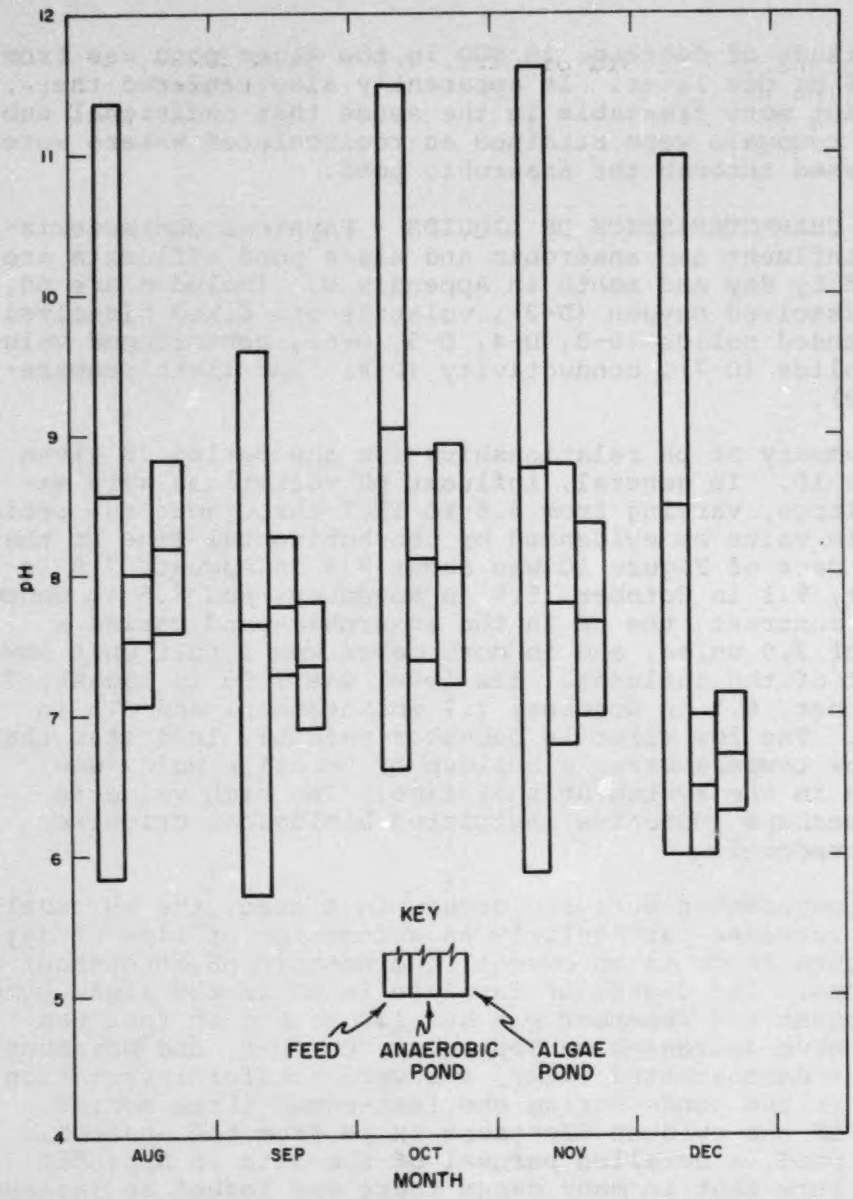

FIGURE 10. EXTREMES AND CENTRAL TENDENCY pH RELATIONSHIP IN INFLUENT, ANAEROBIC AND ALGAE POND AS A FUNCTION OF MONTH

always zero after loading was first applied. Thus, the aeration capability of 307 lbs per day of the floating aerator plus normal reaeration was quickly overwhelmed by the load rate. Also, after about one week of loading and recirculation, the algae pond became devoid of dissolved oxygen during the morning sampling period. Thus, the only data reported in Appendix D-2 are for 3 PM dissolved oxygen in the algae pond. These data are presented graphically in Figure 11.

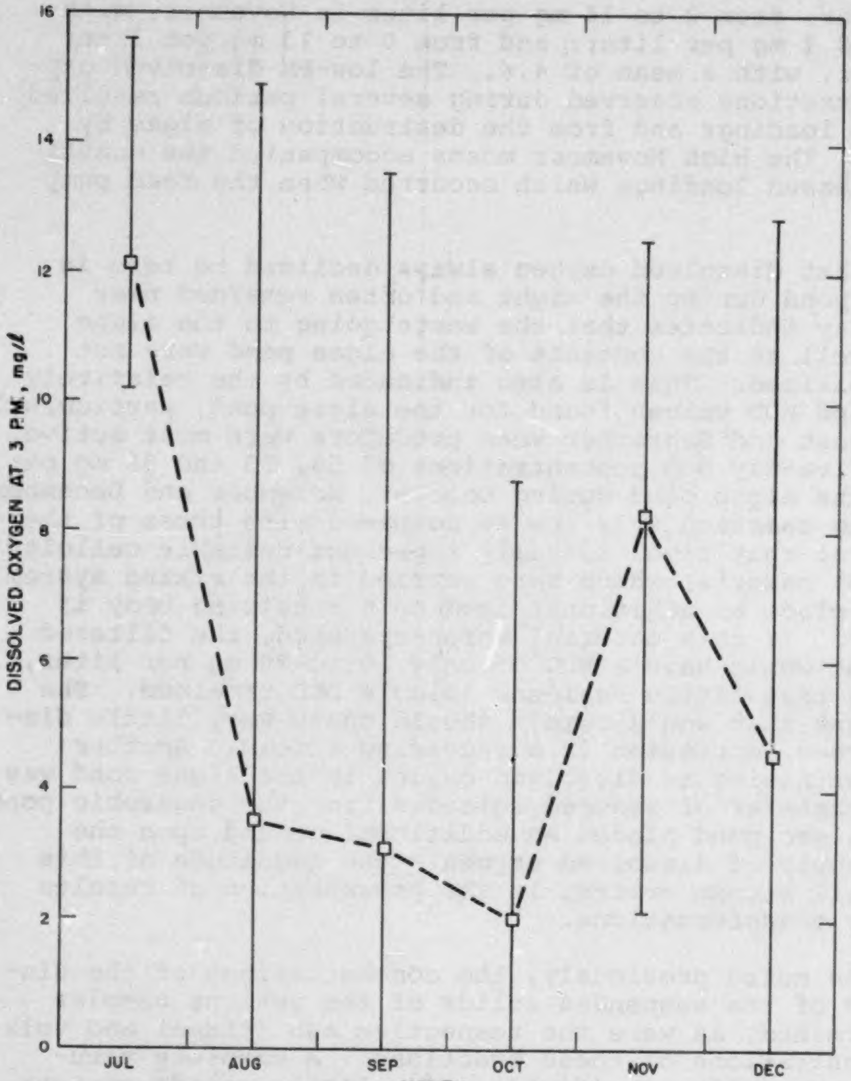

FIGURE 11. MONTHLY MEAN, MAXIMUM, AND MINIMUM DISSOLVED OXYGEN VALUES FOR ALGAE PONDS DAILY AT 3 P.M.

As is evident from the figure, beginning with high values in July, the DO values varied from 0 to 15.9 mg per liter in August with a mean of 3.5 mg per liter; from 0 to 13.6 mg per liter in September with a mean of 3.1 mg per liter; from 0 to 8.8 mg per liter in October, with a mean of 2.0 mg per liter; from 2 to 14 mg per liter in November, with a mean of 8.4 mg per liter; and from 0 to 13 mg per liter in December, with a mean of 4.6. The low-PM dissolved oxygen concentrations observed during several periods resulted from heavy loadings and from the destruction of algae by predators. The high November means accompanied the drastically decreased loadings which occurred when the feed pump failed.

The fact that dissolved oxygen always declined to zero in the algae pond during the night and often remained near zero all day indicates that the waste going to the algae pond, as well as the contents of the algae pond were not fully stabilized. This is also indicated by the relatively high COD and BOD values found for the algae pond, particularly during August and September when predators were most active. The mean five-day BOD concentrations of 56, 55 and 58 mg per liter in the algae pond during October, November and December, while being spectacularly low as compared with those of the influents at that time, actually represent unstable cellular (suspended) material which were carried in the mixing system and would place an additional load on a receiving body if discharged. If this material were separated, the filtered supernatant would have a BOD of only 10 to 20 mg per liter, indicating that little residual soluble BOD remained. The small amount that would remain should cause very little dissolved oxygen depression in a receiving stream. Another problem pertaining to dissolved oxygen in the algae pond was that the transfer of reduced sulfides from the anaerobic pond into the algae pond placed an additional demand upon the limited supply of dissolved oxygen. The magnitude of this problem will become evident in the presentation of results on sulphur transformations.

Solids: As noted previously, the concentrations of the dissolved and of the suspended solids of the various samples were determined, as were the respective ash (fixed) and volatile concentrations of these fractions. A complete tabulation of the daily ash (fixed) and volatile solids content of the dissolved and suspended solids in each pond component and month is presented in Appendices D-3, D-4, D-5 and D-6, and the monthly mean values are summarized in Table 7.

A plot of volatile dissolved solids concentrations from Table 7 as a function of pond and month is shown in Figure 12.

TABLE 7
Summary of Solids Data

Monthly Mean Dissolved Solids mg Per Liter

Month	Volatile			Ash			Total		
	In	An	Al	In	An	Al	In	An	Al
Jul	975	333	268	1039	1164	1149	2014	1497	1417
Aug	1358	520	391	1128	1002	1099	2486	1522	1490
Sep	1150	477	441	1118	922	978	2268	1399	1419
Oct	1250	608	528	946	831	930	2196	1439	1458
Nov	1513	557	507	1215	898	935	2728	1455	1442
Dec	2142	606	523	1129	884	954	3271	1490	1477

Monthly Mean Suspended Solids mg Per Liter

Month	Volatile			Ash			Total		
	In	An	Al	In	An	Al	In	An	Al
Jul	105	84	94	148	19	20	253	103	114
Aug	241	128	156	239	25	27	480	153	183
Sep	378	376	374	465	82	88	843	458	462
Oct	199	452	414	447	155	131	646	607	545
Nov	199	413	369	212	79	75	411	492	444
Dec	327	492	395	472	152	98	799	644	493

Monthly Mean Total Solids mg Per Liter

Month	Volatile			Ash			Total		
	In	An	Al	In	An	Al	In	An	Al
Jul	1080	417	362	1187	1183	1169	2267	1600	1531
Aug	1599	648	547	1367	1027	1126	2966	1675	1673
Sep	1528	853	815	1583	1004	1066	3111	1857	1881
Oct	1449	1060	942	1393	986	1061	2842	2046	2003
Nov	1712	970	876	1427	977	1010	3139	1947	1886
Dec	2469	1098	918	1611	1036	1052	4070	2134	1970

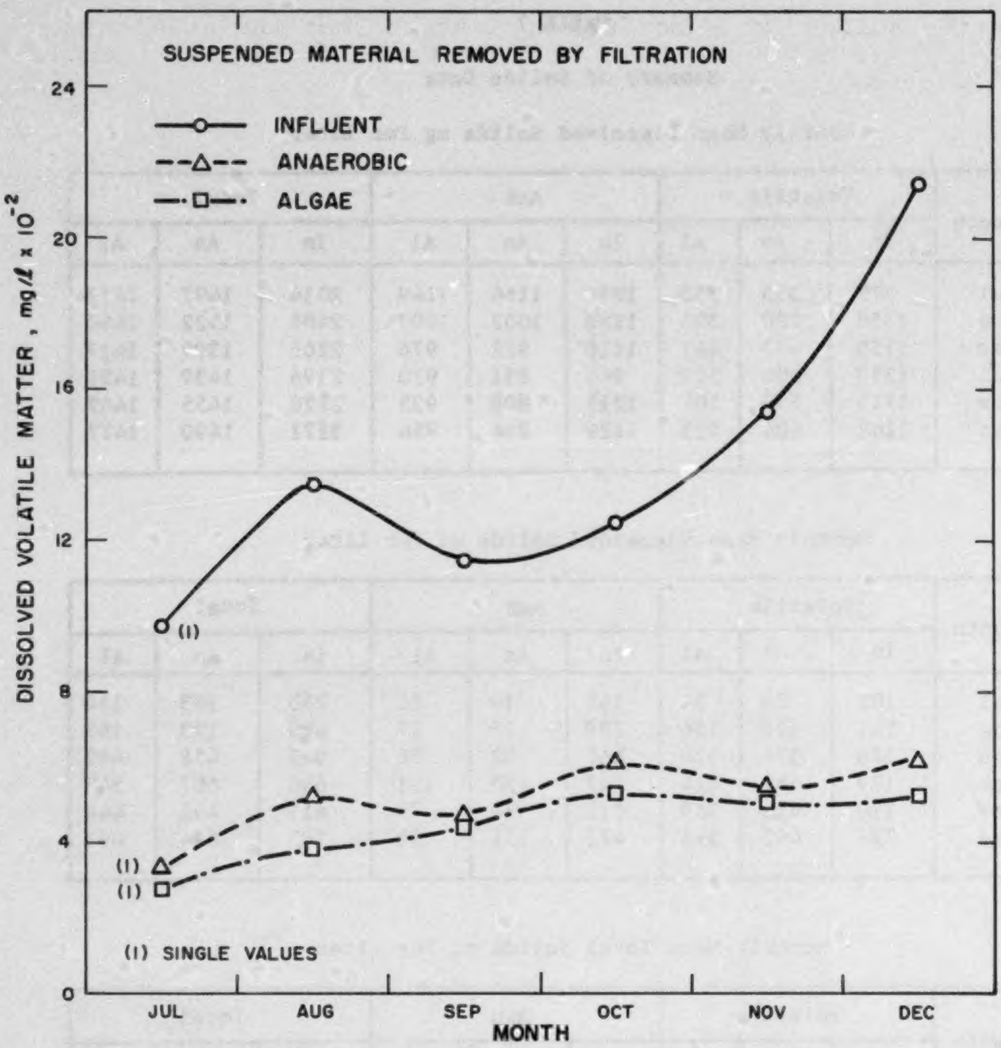

FIGURE 12. MONTHLY MEAN DISSOLVED VOLATILE SOLIDS AS A FUNCTION OF POND AND MONTH

Dissolved volatile solids in the influent varied from 975 mg per liter in July to a mean of 2142 mg per liter in December. This increase in soluble volatile matter probably resulted from a deterioration in beet quality with release of putrescible materials. A similar but even more pronounced increase in solubles was also observed in the filtered COD of the influent discussed previously. Influent dissolved volatiles were decreased by more than 60% in the anaerobic pond, and by an additional approximately 10% in the algae pond. During November and December, the reduction in dissolved volatile solids exceeded 70%, indicating that the soluble fraction was not only greater in magnitude than the insoluble but was also more readily decomposed.

A plot of the dissolved ash is shown in Figure 13. The influent dissolved ash had a mean value of 1096 mg per liter, and with the exception of the October mean, all values were within ± 10% of this value. The October value was minus about 15%. A definite downward trend is evident in the dissolved ash concentration in the anaerobic pond and in the algae pond, indicating a precipitation of some relatively heavy material. The drop was greater in the anaerobic pond than in the algae pond, indicating that a degree of reconcentration, perhaps due to evaporation, occurred in the algae pond.

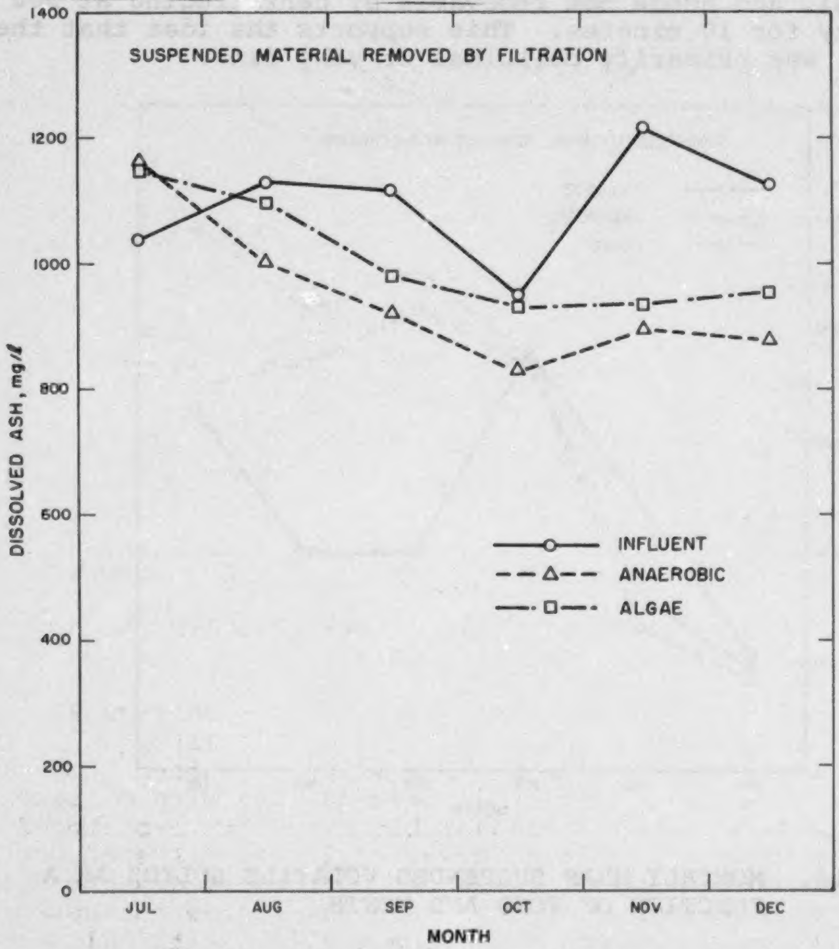

FIGURE 13. MONTHLY MEAN DISSOLVED ASH AS A FUNCTION OF POND AND MONTH

A plot of suspended volatile solids is shown in Figure 14. While the mean influent suspended volatile concentrations were quite erratic, they were generally significantly less than those in the anaerobic and algae pond. The buildup of suspended volatiles in both the anaerobic and algae pond was at a rate typified by a growth curve. The greatest concentration of suspended volatiles occurred in the anaerobic pond in December. As would be expected, an examination of the packed centrifuged solids (cf. Appendix D-7 and Figure 15) indicated that this suspended material was primarily bacterial in nature in the anaerobic pond, and primarily algae material in the algae pond. It is interesting to note that the overall packed volume was greatest in the algae pond, indicating that the suspended solids in both the influent and anaerobic pond were mainly finally divided or colloidal, and hence not removable by centrifuging at 500 x gravity for 10 minutes. This supports the idea that the material was primarily colloidal or very fine.

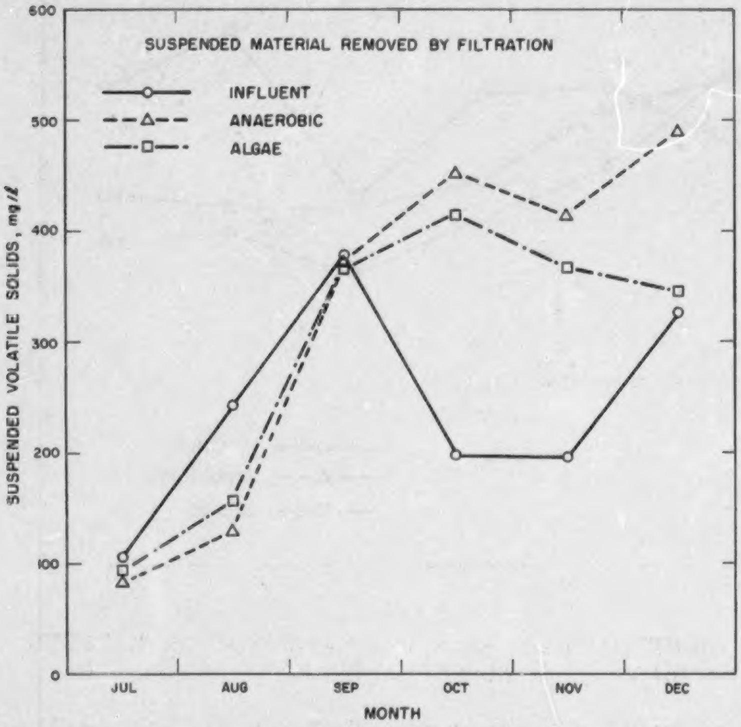

FIGURE 14. MONTHLY MEAN SUSPENDED VOLATILE SOLIDS AS A FUNCTION OF POND AND MONTH

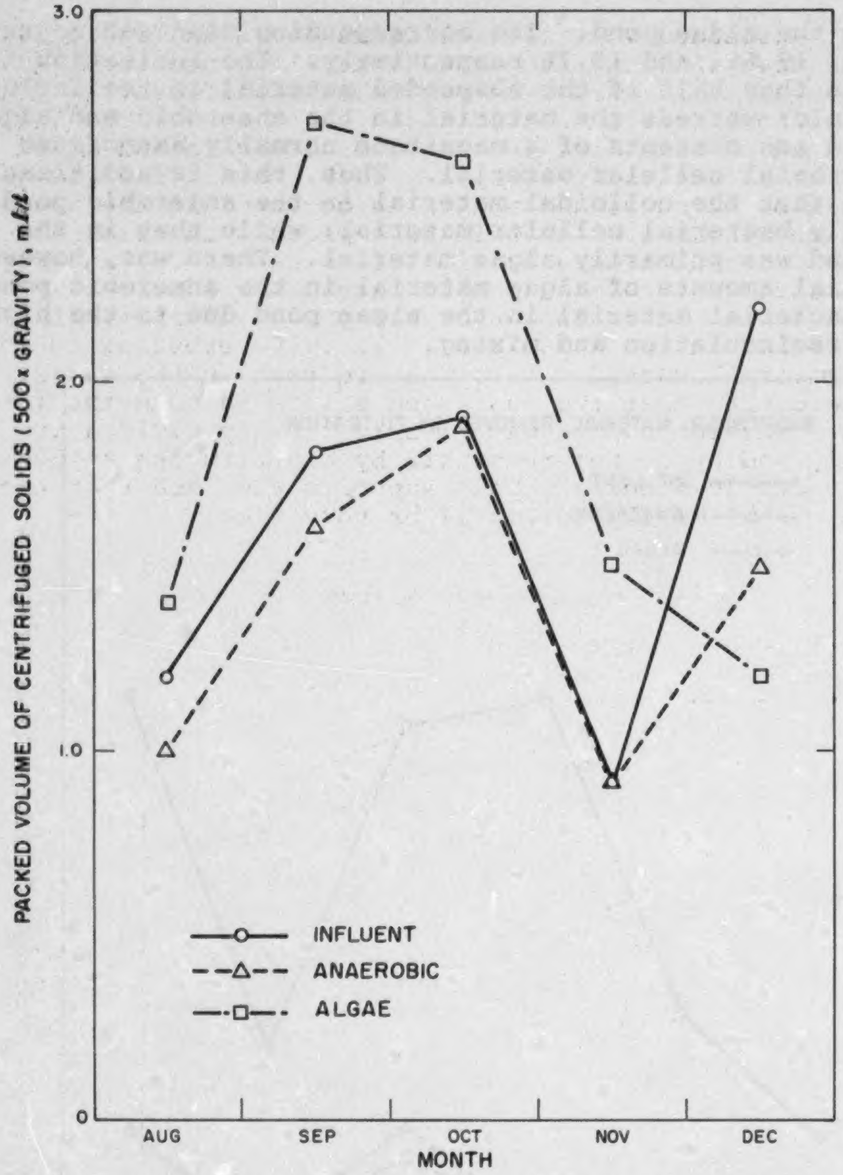

FIGURE 15. MONTHLY MEAN PACKED VOLUME OF CENTRIFUGED SOLIDS AS A FUNCTION OF POND AND MONTH

A plot of the monthly mean suspended ash in the influent and two ponds is shown in Figure 16. As is evident from the figure, the concentration of suspended ash in the influent was much higher than that in the pond suspended material ranging from 50% to 69% in the influent, from 16.0% to 25.4% in the anaerobic pond, and from 14.8 to

24.0% in the algae pond. The corresponding mean ash contents were 57%, 19.6%, and 18.7% respectively. The indication is that less than half of the suspended material in the influent was organic; whereas the material in the anaerobic and algae ponds had ash contents of a magnitude normally associated with microbial cellular material. Thus, this is additional evidence that the colloidal material in the anaerobic pond was mainly bacterial cellular material; while that in the algae pond was primarily algae material. There was, however, substantial amounts of algae material in the anaerobic pond, and of bacterial material in the algae pond due to the high rate of recirculation and mixing.

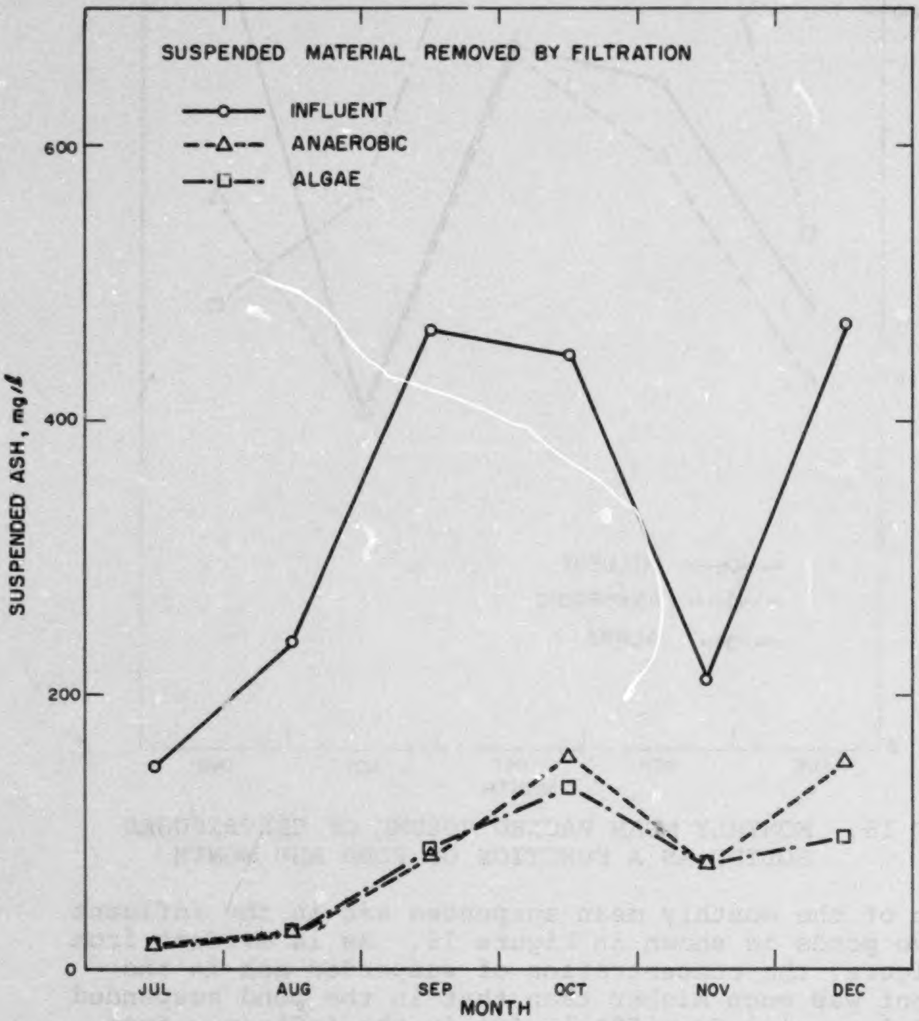

FIGURE 16. MONTHLY MEAN SUSPENDED ASH AS A FUNCTION OF POND AND MONTH

Conductivity: Daily and monthly mean values for conductivity are shown in Appendix D-8 and means are plotted in Figure 17. Although the influent conductivity varied, it oscillated around a mean value of about 310 micro mhos, whereas the conductivity of the algae pond and the anaerobic pond steadily increased throughout the run period. At first glance this could be attributed to a simple salt concentration factor due to evaportaion; but a comparison of the monthly mean dissolved ash and the monthly mean conductivity of the three sampling points indicates that there was a substantial change in the physical nature of the solids in the ponds. Thus, in the algae pond and in the anaerobic pond, a smaller quantity of dissolved ash was associated with higher specific conductance than was true in the influent. This effect was slightly more pronounced in the anaerobic pond than in the algae pond.

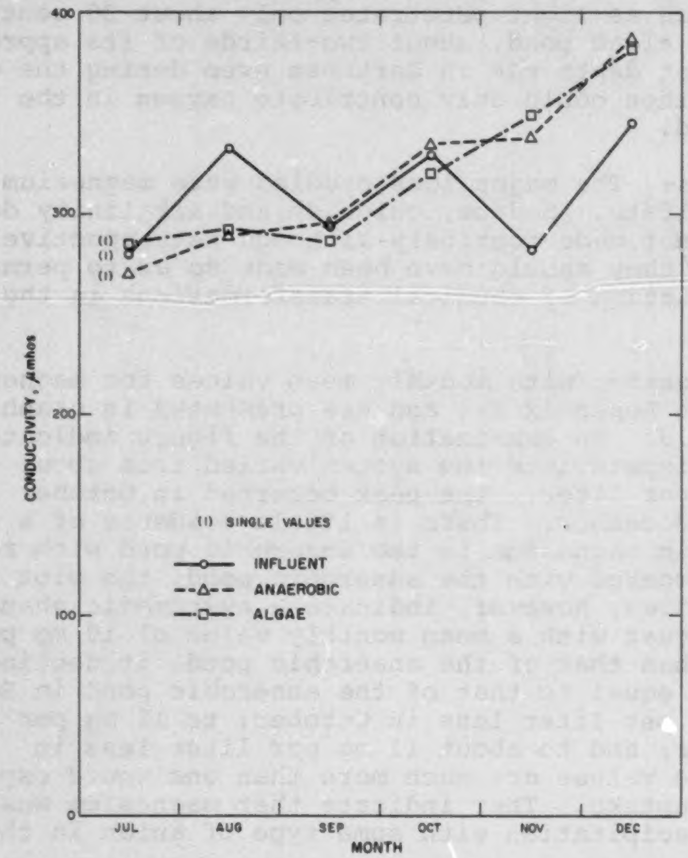

FIGURE 17. MONTHLY MEAN CONDUCTIVITY AS A FUNCTION OF POND AND MONTH

Light Penetration: Values found in measurements of light penetration through the influent and pond contents are tabulated in Appendix D-9 and the monthly mean values are plotted in Figure 18. As is indicated in the figure, following a month of operation, light transmission was greatest in the influent and least in the anaerobic pond. Intermediate transmittance was attained in the algae pond. Both complexed sulfides and algae strongly absorb light. Algae and sulfides occurred in the anaerobic pond and light absorption was due to both. Inasmuch as algae constituted the major portion of suspended solids in the algae pond, light absorption was mainly by algae when oxygen was present. When dissolved oxygen was very low, turbidity from metal sulfides absorbed much of the light. Also, inasmuch as the pond was mixed, some of the light absorption probably was due to clay turbidity induced by the mixing velocity of about one foot per second. Inasmuch as light penetrated only about 30 centimeters into the algae pond, about two-thirds of its approximately three-foot depth was in darkness even during the day. Photosynthesis then could only contribute oxygen in the top foot of the pond.

Chemical Changes: The major ions studied were magnesium, calcium, and sulfate. Sodium, chloride, and alkalinity determinations were not made routinely although retrospectively it is felt that they should have been made so as to permit a complete evaluation of chemical transformations in the system.

Daily values together with monthly mean values for magnesium are tabulated in Appendix E-1 and are presented in graphic form in Figure 19. An examination of the figure indicates that magnesium inputs into the system varied from about 40 to about 75 mg per liter. The peak occurred in October and the minimum in December. There is little evidence of a systematic change in magnesium in the anaerobic pond with respect to time. If compared with the anaerobic pond, the plot for the algae pond does, however, indicate a systematic change. Beginning in August with a mean monthly value of 10 mg per liter greater than that of the anaerobic pond, it declined to values about equal to that of the anaerobic pond in September; to 5 mg per liter less in October; to 15 mg per liter less in November; and to about 11 mg per liter less in December. These values are much more than one would expect for biological uptake. They indicate that magnesium was undergoing a precipitation with some type of anion in the algae pond.

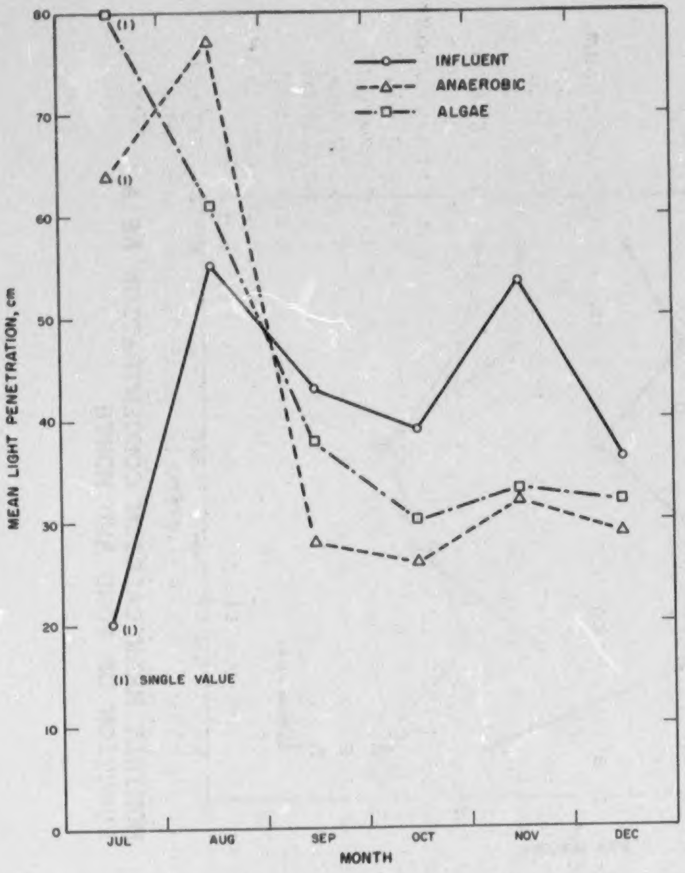

FIGURE 18. MONTHLY MEAN LIGHT PENETRATION AS A FUNCTION OF POND AND MONTH

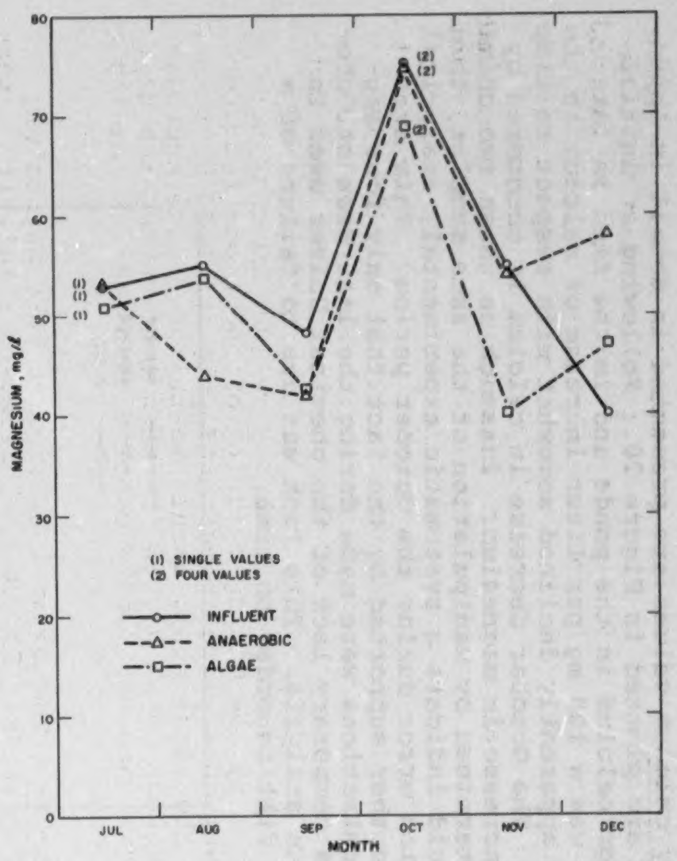

FIGURE 19. MONTHLY MEAN MAGNESIUM CONCENTRATION AS A FUNCTION OF POND AND MONTH

Mean monthly calcium values are presented in detail in Appendix E-2 and are plotted in Figure 20. Following an initial low value for calcium in the ponds and in the feed in late July, there was a 100 mg per liter increase of calcium in the feed. This apparently declined somewhat with respect to time thereafter. The October decrease in calcium is countered by a similar increase in magnesium. Inasmuch as these two chemicals are determined by manipulation of the same samples, this relation could indicate a systematic experimental, analytical or calculation error during the October period. This eventually is further supported by the fact that only four magnesium determinations were made during the last week of October due to a temporary lack of the chemical Univer used in the magnesium analysis. This lack was due to failure of a supplier to fill an order on time.

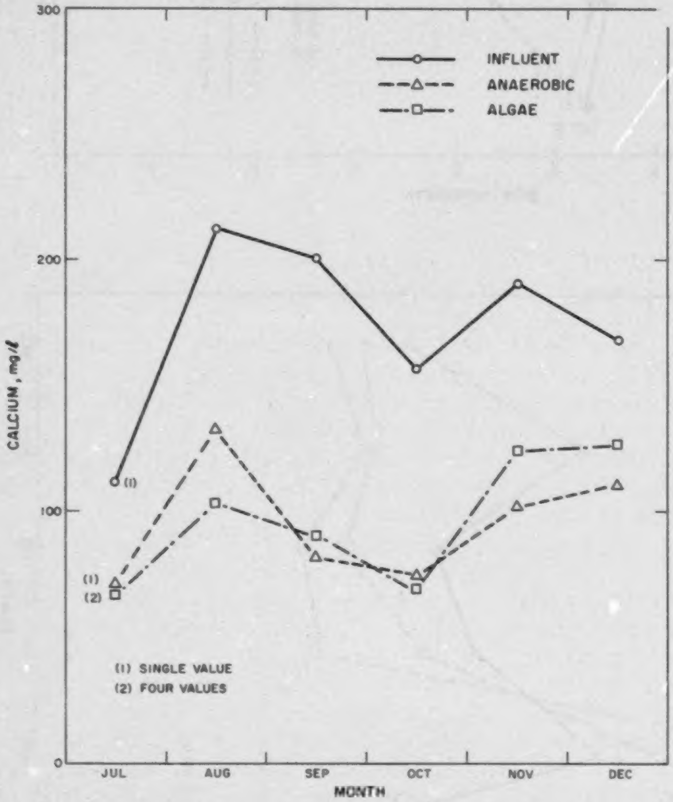

FIGURE 20. MONTHLY MEAN CALCIUM CONCENTRATION AS A FUNCTION OF POND AND MONTH

In spite of these difficulties, the evidence is clear that a decrease in calcium occurred following the introduction of the waste into the anaerobic pond. The magnitude of the change involved about 50% of the influent calcium. This probably was due to precipitation and sedimentation of suspended colloidal calcium. Apparently no systematic increase or decrease of calcium took place in the transfer from the anaerobic pond to the algae pond, as was the case with magnesium. Thus, the evidence is that calcium decreased most substantially in the anaerobic pond, and magnesium decreased most substantially in the algae pond. With respect to the microbial and algae nutrition aspect of the problem, it is evident that both calcium and magnesium were present in vast excess.

The cation ammonium was systematically studied in these experiments. Results pertaining to it are presented in the discussions of the other nutrients. The only major anion systematically studied was sulfate. The minor anions nitrate and phosphate also were studied. These results are also presented in conjunction with those for other nutrients. Daily and monthly mean values for sulfate are tabulated in Appendix E-3, and monthly mean values are plotted as a function of pond and month in Figure 21.

An examination of Figure 21 indicates that during the course of the experiments, influent sulfate concentration rose slightly during August and September (from 215 to 265 mg per liter), and then declined from September through December (from about 250 to about 150 mg per liter). In the anaerobic pond a steady decline in sulfate took place from an initial level of about 120 mg per liter in July to about 60 mg per liter in September. In the period from September to December, sulfate in the anaerobic pond increased slightly (about 10 mg per liter). A sulfate removal in excess of 50% was effected in the anaerobic pond.

Sulfate concentration in the algae pond ranged from 10 to 35 mg per liter greater than that in the anaerobic pond, the mean increasing being about 25 mg per liter. The presence of more oxidized sulfur in the algae pond than in the anaerobic pond indicates that sulfate was first reduced in the anaerobic pond to sulfides and then oxidized to sulfate in the algae pond. This, of course, indicates that insoluble sulfides moved from the anaerobic pond into the algae pond in substantial quantities. The form in which these sulfides moved is of some interest and will be discussed later.

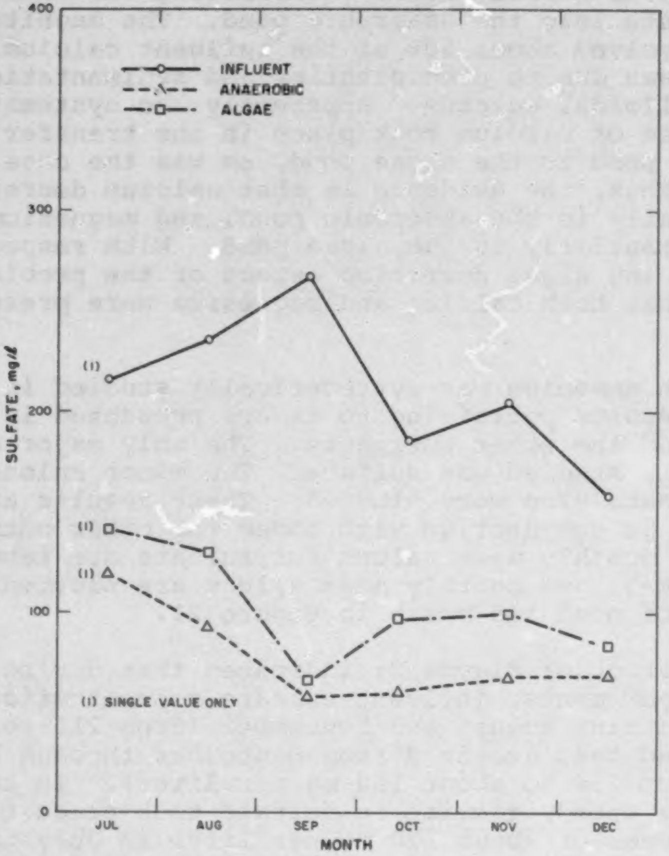

FIGURE 21. MONTHLY MEAN VALUES FOR SULFATE AS A FUNCTION OF POND AND MONTH

According to the available data, it would also be informative to relate sulfate reduction to temperature. In Figure 22, monthly mean sulfate reduction is plotted as a function of monthly mean temperature in the anaerobic pond. As shown in the figure, the sulfate reduction is a linear function of temperature between 10 and 25°C, the relationship being

$$R\% = 55 + 2\ (T - 10) \qquad (1)$$

This relationship did not hold in August when the ponds were first started, but it did hold during September, October, November, and December. The dotted line in Figure 22 indicates the probable general relationship between temperature and sulfate reduction, but the data are insufficient to support or disprove this hypothetical relationship.

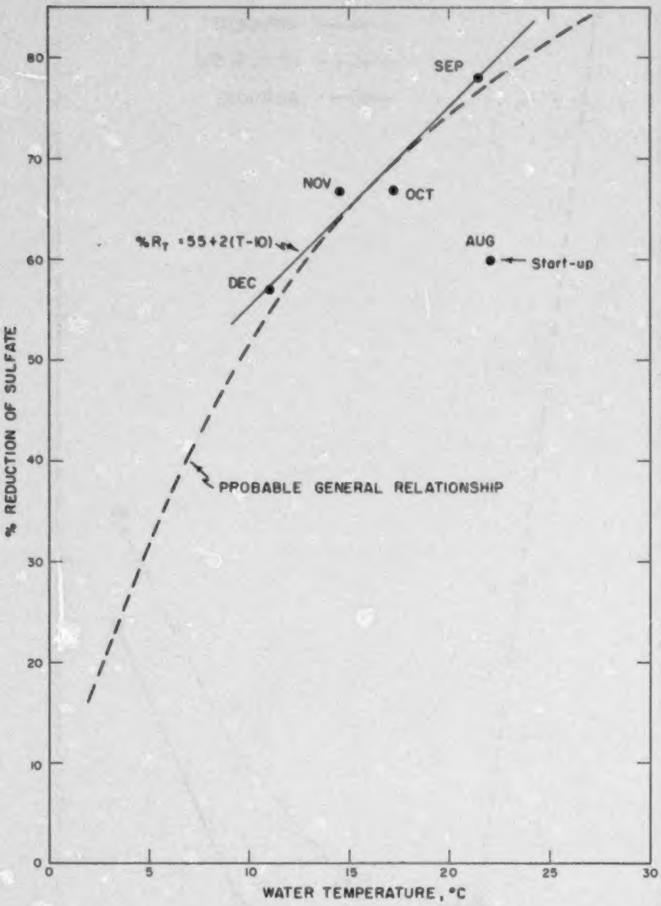

FIGURE 22. SULFATE REDUCTION IN ANAEROBIC POND AS A FUNCTION OF TEMPERATURE

Other factors related to sulfate reduction are presented in the section "Discussion".

Daily and monthly mean sulfide determinations for the period August through December for the influent and the two ponds are presented in Appendix E-4 and a plot of the monthly mean values is presented in Figure 23. As shown in the figure, daily values for soluble sulfides were initially quite high. Some concentrations in the anerobic pond were found to be as much as 6 mg per liter during August. These concentrations decreased rapidly as the loading progressed, indicating that those sulfides produced from sulfate reduction were

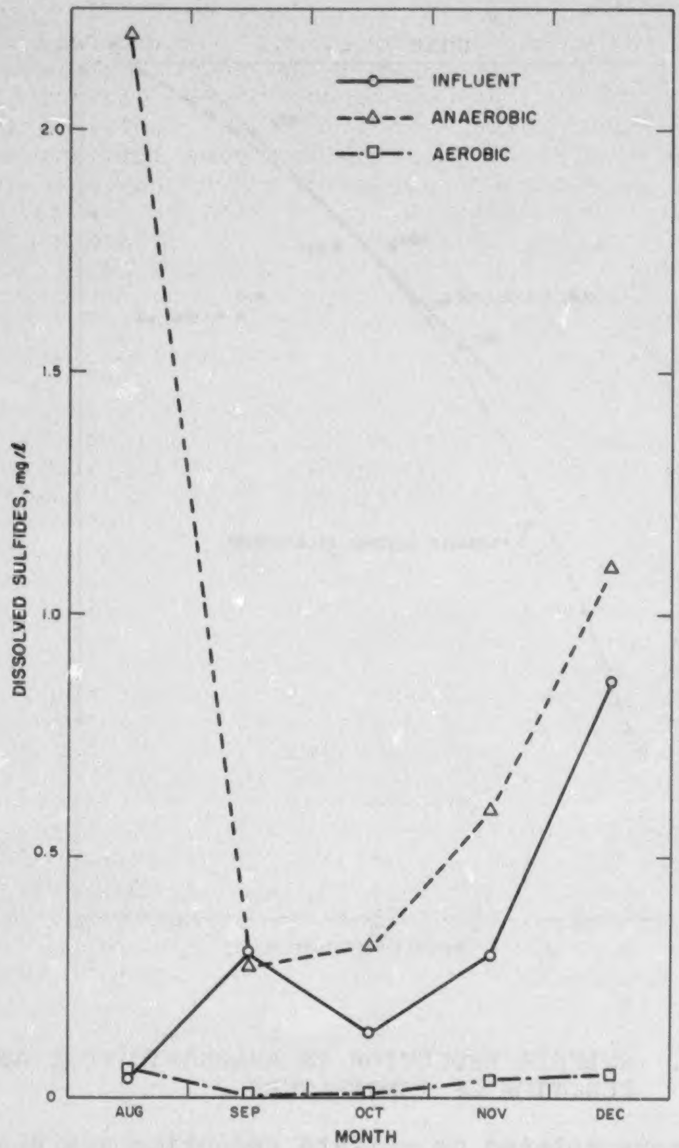

FIGURE 23. MONTHLY MEAN DISSOLVED SULFIDES AS A FUNCTION OF MONTH

rapidly complexed or combined with some substance contributed by the applied waste. A regression analysis of the daily sulfide and magnesium values indicates a correlation of +88% between the two; whereas correlations between other factors were much lower. Thus, it is believed likely that the form in which the sulfides were carried from the anaerobic pond to the algae pond was in the form of insoluble but suspended magnesium sulfide. Once in the algae pond where oxygen was frequently in excess, this material probably was oxidized to magnesium sulfate. Inasmuch as magnesium sulfate is soluble, the magnesium would then be free to interact with other anions to produce less soluble complexes such as magnesium hydroxide and thereby lead to the slight reduction in magnesium in the algae pond noted in the magnesium results presented previously.

The increase in sulfides from influent to the anaerobic pond shown in Figure 23 is to be expected in view of the sulfate reduction depicted in Figure 21. An absence or low level of sulfides in the algae pond is evidenced in the figure and is to be expected in view of the generally aerobic environment of the algae pond.

Through a comparison of the monthly mean dissolved sulfides in the system with the BOD removal in the system as set forth in Table 6, an apparent relationship between loading and dissolved sulfides becomes apparent. The relationship is plotted in Figure 24. According to the figure, with the exception of concentrations observed during November during which loading was interrupted and sporadic, dissolved sulfides concentrations were inversely proportional to the loading, attaining a maximum in August when the loading was at its maximum. The dotted line indicates a hypothetical relationship between loading and soluble sulfides as suggested by the data. The indication is that loadings above 1,000 lbs per acre per day will be accompanied by increasing quantities of dissolved sulfides; and hence, by increasing odors. On the other hand, loadings below 1,000 lbs per acre per day will be accompanied by dissolved sulfides concentrations less than 0.025 mg per liter and less odor. Obviously, such a relationship would be affected by the amount of influent sulfate, the types and quantities of sulfide, complexing substances in the waste, and the temperature. Hence, it would be subject to considerable geographical variation depending on climate, factory location, water quality, soil type, beet conditions, and so on.

Sulfide is not the only reduced substance in beet sugar waste responsible for malodors. Volatile acids and alcohols are malodorous, and their odor cannot be measured by merely measuring sulfides. Therefore, the organoleptic or "smell" test was systematically applied to daily samples of the waste or effluents from various parts of the system.

All organoleptic odor products measured during the campaign are tabulated in Appendix E-5 and the monthly mean values for influent, anaerobic, and algae pond are plotted as a function of month in Figure 25. As is evident from the figure, the odor product of the influent increased during August, September, and October; decreased slightly in November, and then decreased rapidly in December. In the anaerobic pond odors

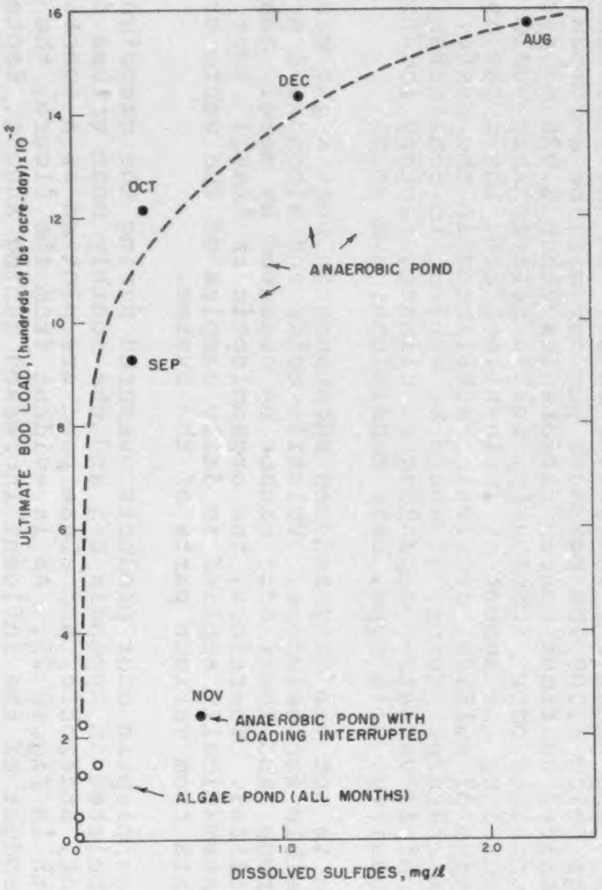

FIGURE 24. DISSOLVED SULFIDES AS A FUNCTION OF ABSORBED BOD LOAD

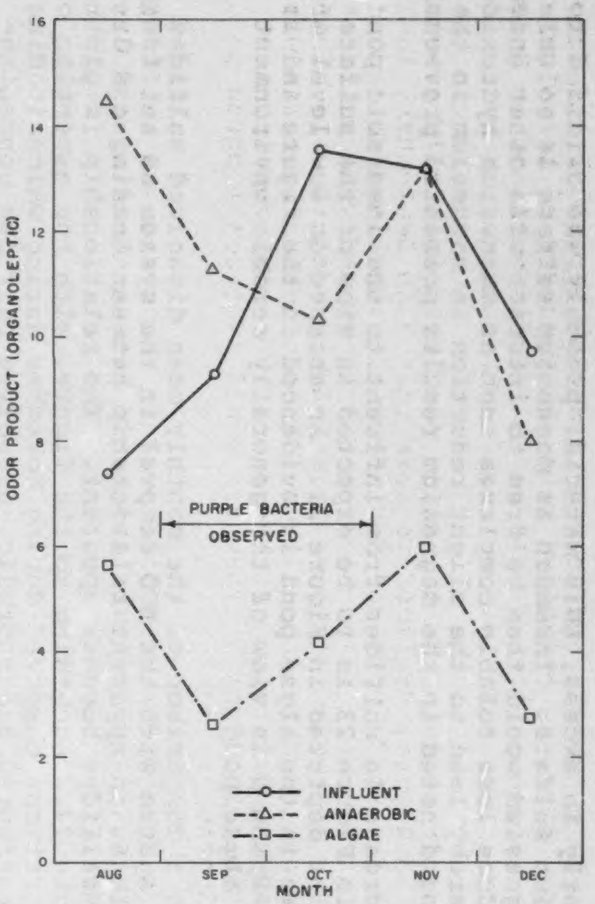

FIGURE 25. MEAN ODOR PRODUCT AS A FUNCTION OF MONTH FOR INFLUENT, ANAEROBIC AND ALGAE PONDS

were high in August, and decreased during September and October. The decrease coincided with the presence of large numbers of purple bacteria. The product again declined in December, probably because of decreased temperature.

Mean values for odor in the algae pond were initially greater than 6 in August, declined to less than 3 in September, increased during October and November, then declined to less than 3 in November. The algae pond rarely had what would be termed an objectionable odor, even when predators were making inroads on the algae population. Purple sulfur bacteria were found in the algae pond at the times when they were present in the anaerobic pond. They too could have contributed to the reduction in odor.

The relationship between odor product and dissolved sulfides may be visualized by comparing these two parameters as shown in Figure 26.

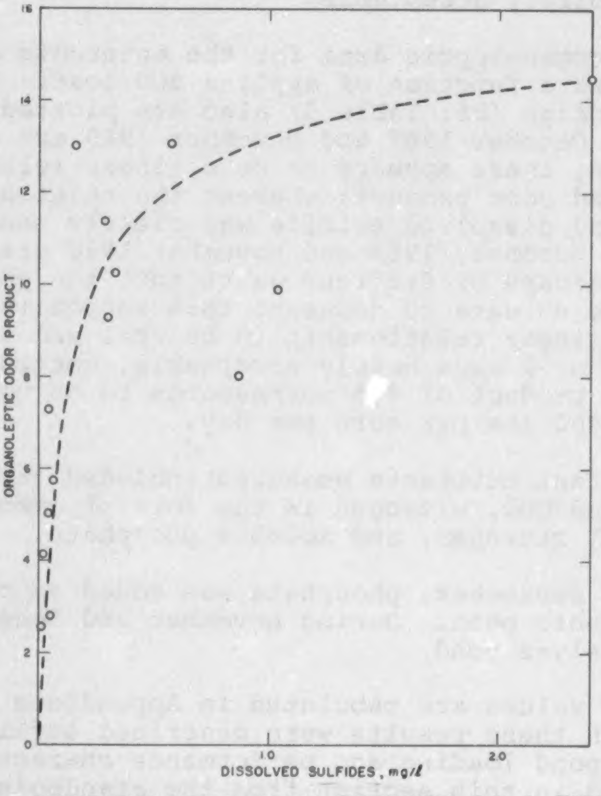

FIGURE 26. MONTHLY MEAN ODOR PRODUCT AS A FUNCTION OF MONTHLY MEAN DISSOLVED SULFIDES

As is evident from the figure, a positive correlation exists which probably is nonlinear. However, because of the scattered data, it is not possible to conclude any point of inflection. In the case of data from influent daily samples, odor products as high as 16 were accompanied by a "0" dissolved sulfide determination. Inasmuch as the influent had a higher temperature than the ponds, it seems likely that at times it was assigned a higher odor intensity factor than the ponds. Also, metal complexes of sulfide form more readily at high temperatures and this would decrease the sulfide in the influent. In the case of the anaerobic pond, in one sample an odor product of 24 was accompanied by a sulfide concentration of 0.1 mg per liter. Thus, as is well known, and is also evident from these data, many odorous substances other than H_2S are formed in the decomposition of beet wastes. The question then arises: What odor product would be acceptable if the hydrogen sulfide level were almost 0? Unfortunately, the data do not permit more than the tentative supposition that a level of 8 or 9 may be barely acceptable.

In Figure 27 the organoleptic data for the anaerobic and algae pond are plotted as a function of applied BOD load. Data from the 1967 fall campaign (cf. Table 3) also are plotted. If the exceptions of October 1967 and November 1968 are excluded from consideration, there appears to be a linear relationship between loading and odor product; whereas the relationship between loading and dissolved sulfide was clearly non-linear. The exceptions of October, 1967 and November 1968 are believed to be due to the escape of Steffens waste into the ponds. However, there are no data to document this supposition. If one assumes this linear relationship to be real and that an odor product of 8 or 9 were barely acceptable, according to the graph an odor product of 8.5 corresponds to an ultimate BOD loading of 1,000 lbs per acre per day.

Nutrients: The plant nutrients measured included carbon in the form of BOD and COD, nitrogen in the form of ammonia, nitrate, and total nitrogen; and soluble phosphate.

During August and September, phosphate was added as phosphoric acid to the anaerobic pond. During November and December, it was added to the algae pond.

Daily COD and BOD values are tabulated in Appendices C-1, C-2, and C-3. Although these results were described earlier in conjunction with pond loading and performance characteristics, they are presented in this section from the standpoint of BOD and COD as nutrient parameters.

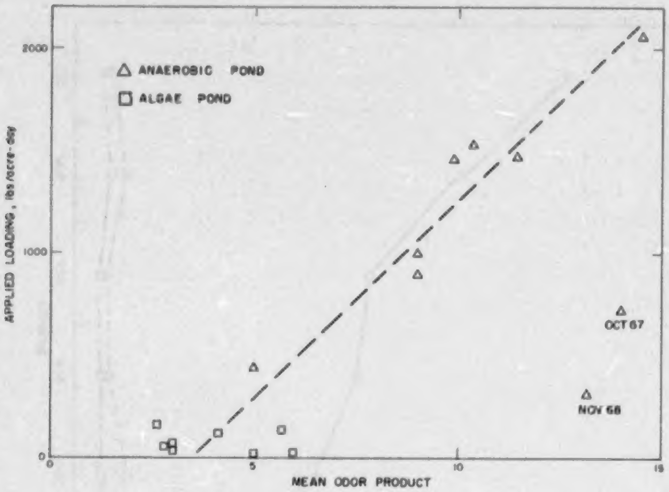

FIGURE 27. MONTHLY MEAN ORGANOLEPTIC ODOR PRODUCT AS A FUNCTION OF APPLIED AREAL LOADING

The monthly mean values for unfiltered COD in the influent, the anaerobic pond and algae pond are graphed in Figure 28. As is evident from the figure, unfiltered COD in the influent and in the two ponds increased steadily during the fall campaign. However, with respect to time, an increased fraction of the unfiltered COD was removed in the ponds.

Mean values for filtered COD are presented as a function of pond and month in Figure 29. From this figure, it is evident that although the COD of filtered influent samples increased steadily during the campaign, the COD of filtered anaerobic pond and algae pond contents remained virtually constant between 100 and 200 mg per liter. A plot of the ratio of soluble COD to insoluble COD is shown in Figure 30. Judging from these results, the waste applied had a higher and higher fraction of soluble decomposable matter, probably reflecting the deterioration of beets during the fall. On the other hand, the treated material had a decreasing amount of soluble decomposable matter, reflecting the effectiveness of the treatment.

In the case of the anaerobic pond, beginning with the ratio of 45% soluble in July, an increase to 55% took place in August, followed by a decrease to about 20% in September, October, November, and December. In the case of the algae pond, the COD was initially 95% in the filterable form; whereas by the third month, only about 20% filterable or soluble COD remained.

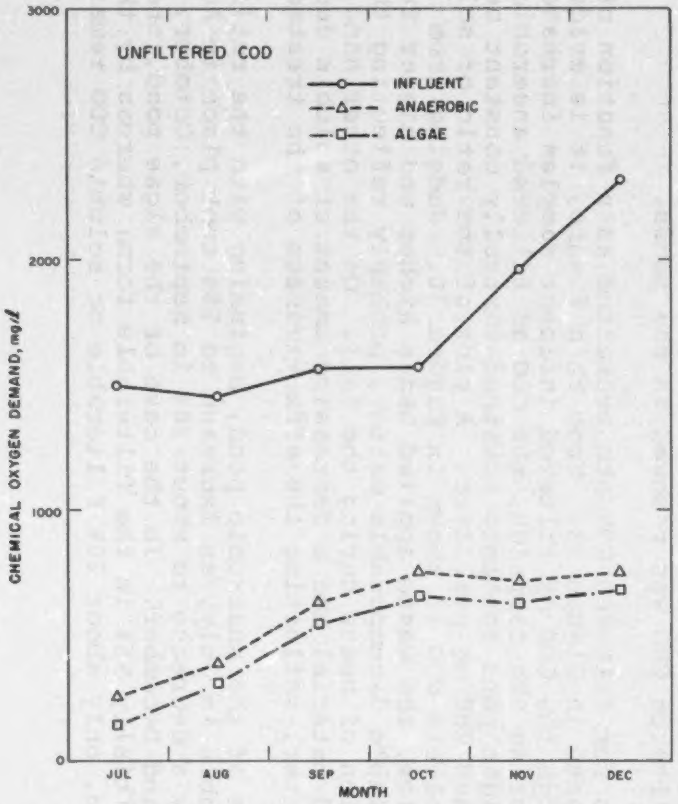

FIGURE 28. MONTHLY MEAN VALUES FOR UNFILTERED COD AS A FUNCTION OF POND AND MONTH

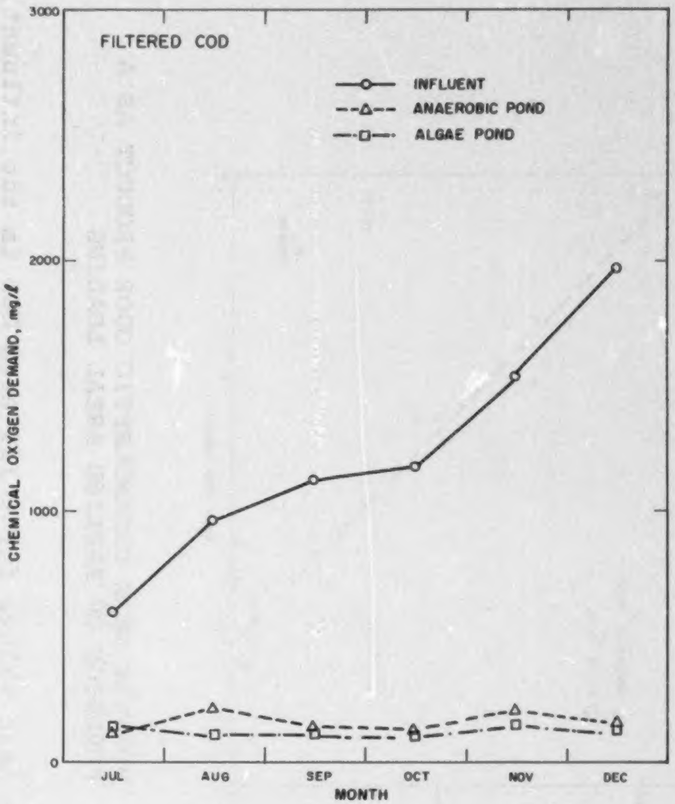

FIGURE 29. MONTHLY MEAN VALUES FOR FILTERED COD AS A FUNCTION OF POND AND MONTH

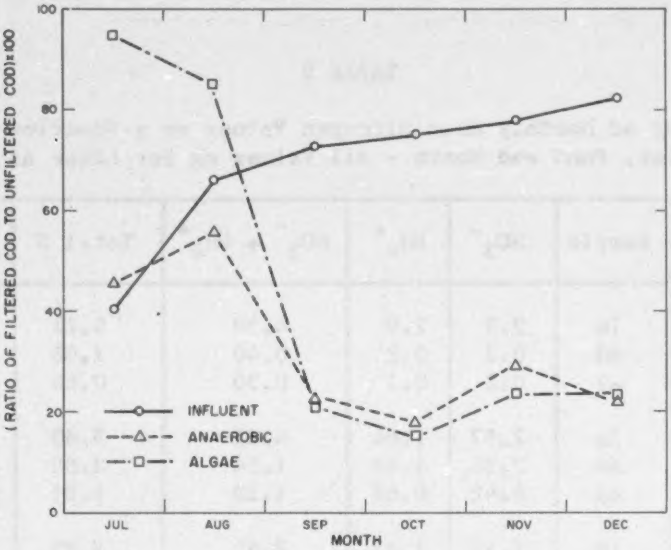

FIGURE 30. RATIO OF MONTHLY MEAN FILTERED TO UNFILTERED COD AS A FUNCTION OF POND AND MONTH

Soluble COD is normally about 42% carbon. Based on this percentage, the soluble organic carbon in the influent was 253 mg per liter in July, 404 mg per liter in August, 474 mg per liter in September, 495 mg per liter in October, 647 mg per liter in November, and 827 mg per liter in December. Using the same ratio, the concentrations in the anaerobic pond averaged 50 mg per liter in July, 91 mg per liter in August, 60 mg per liter in September, 57 mg per liter in October, 88 mg per liter in November, and 69 mg per liter in December. The algae pond concentration averaged 60 mg per liter in July, 47 mg per liter in August, 49 mg per liter in September, 44 mg per liter in October, 63 mg per liter in November, and 55 mg per liter in December. Even the relatively small amount of 40 mg per liter of soluble carbon is high when compared with tentative discharge standards for carbon in most states.

Nitrogen: Daily values for nitrate nitrogen, ammonia nitrogen and total nitrogen are given in Appendices F-1, F-2, and F-3 respectively and are summarized in Table 8.

For clarity of discussion, values from Table 8 are plotted according to nitrogen species as a function of pond and month. Total nitrogen is plotted in Figure 31. The evidence from Figure 31 indicates that a substantial decrease in nitrogen occurred during decomposition of influent in the anaerobic pond; but that as time went by, a substantial accumulation

TABLE 8

Summary of Monthly Mean Nitrogen Values as a Function of Species, Pond and Month - All Values Mg Per Liter as N

Month	Sample	NO_3^-	NH_4^+	$NO_3^- + NH_4^+$	Total N	Diff[1]
Jul[2]	In	2.3	2.0	4.30	5.25	0.95
	An	0.2	0.2	0.40	1.40	1.00
	Al	0.2	0.1	0.30	0.60	0.30
Aug	In	2.97	1.64	4.61	5.60	0.99
	An	0.36	1.18	1.54	2.60	1.06
	Al	0.42	0.68	1.10	1.81	0.71
Sep	In	1.45	1.17	2.62	4.85	2.23
	An	0.42	0.58	1.00	3.78	2.78
	Al	0.40	0.30	0.70	4.23	3.53
Oct	In	3.20	1.38	4.58	4.77	0.19
	An	0.51	0.79	1.30	4.22	2.92
	Al	0.50	0.54	1.04	4.30	3.25
Nov	In	4.31	2.76	7.07	9.28	2.21
	An	0.48	1.63	2.11	6.21	4.10
	Al	0.55	1.31	1.86	5.44	3.58
Dec	In	3.14	1.54	4.68	7.53	2.85
	An	0.45	1.30	1.75	5.77	4.02
	Al	0.67	1.10	1.77	6.25	4.48

[1] The difference is assumed to be organic N plus nitrite N, the latter usually being negligible in magnitude.

[2] July values are singles or duplicates only, all others are means of 10 - 20 values.

of total nitrogen took place in the pond liquids. The concentration increased from about 1 mg per liter in July to about 6 mg per liter in December.

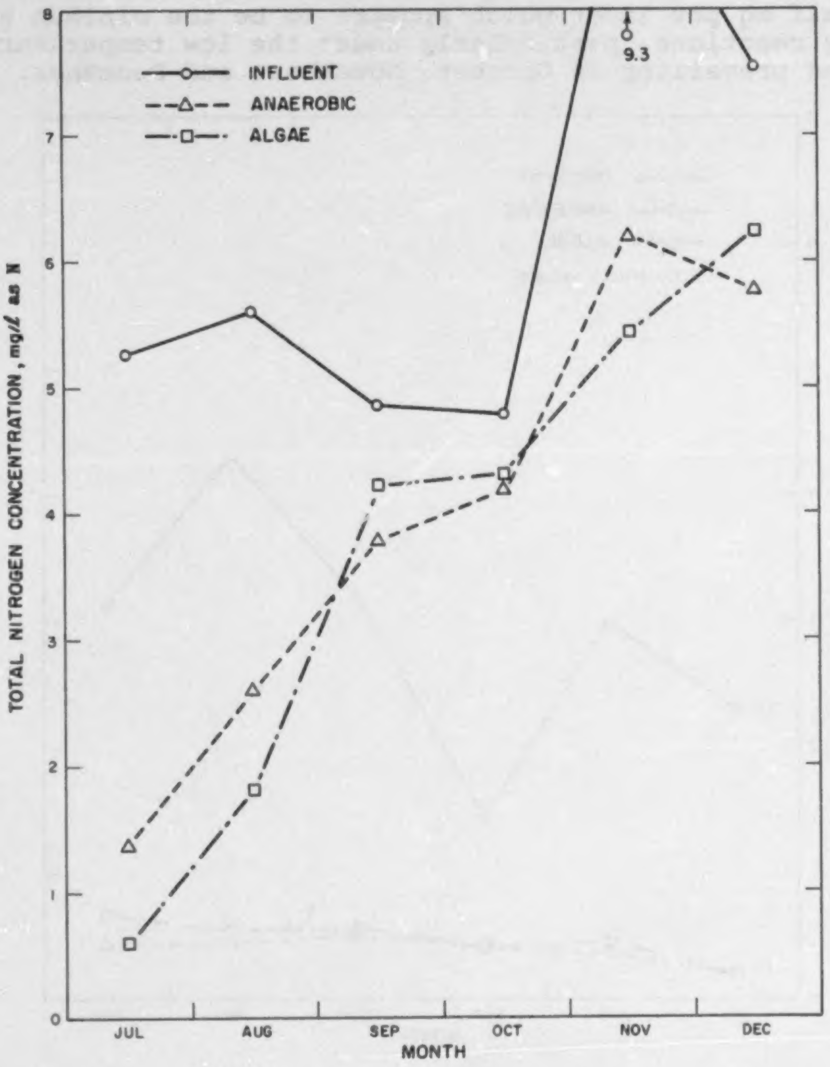

FIGURE 31. MONTHLY MEAN TOTAL NITROGEN VALUES AS A FUNCTION OF POND AND MONTH

The forms of the nitrogen are of interest. Monthly mean values for nitrate-nitrogen as a function of pond and month are shown in Figure 32. Influent nitrate concentrations probably are those contained in the factory fresh water supply and are relatively small, varying from 1.5 to 4.2 mg per liter. The data indicate, as would be expected, that essentially all of this nitrate was reduced to a residual of about one-half mg per liter which appears to be the minimum attained in the reactions, particularly under the low temperature conditions prevailing in October, November, and December.

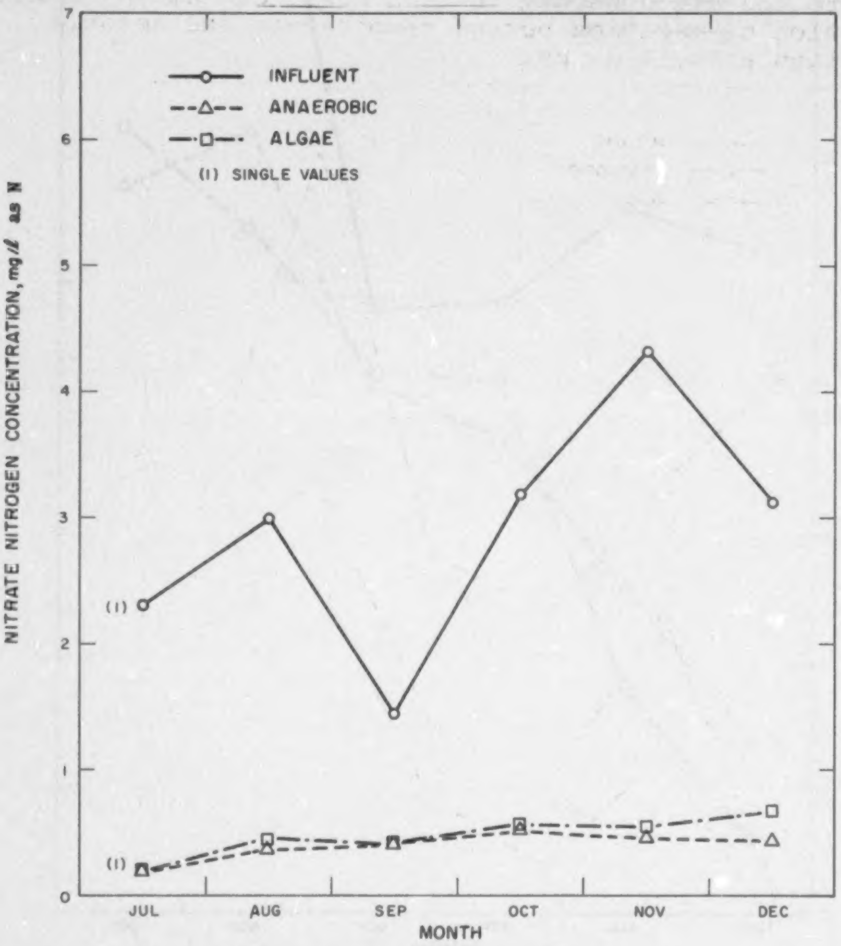

FIGURE 32. MONTHLY MEAN VALUES FOR NITRATE NITROGEN AS A FUNCTION OF POND AND MONTH

Monthly mean ammonia-nitrogen values are plotted in Figure 33. Influent concentrations were erratic, and the mean values varied from about 1.2 to about 2.8 mg per liter. A significant decrease took place in ammonia from influent to anaerobic pond and from anaerobic pond to algae pond. Ammonia-nitrogen apparently increased slightly in the ponds with respect to time. Inasmuch as the pH of the anaerobic pond varied from 7.1 to 8.8 (cf. Appendix D-1) it is possible that at pH values above 8.5 the sustained surface aeration to which the anaerobic pond was subjected led to the loss of some NH_3 to the atmosphere. In each case loss of NH_3 would be a function of aeration period temperature and ammonia concentration as well as pH.

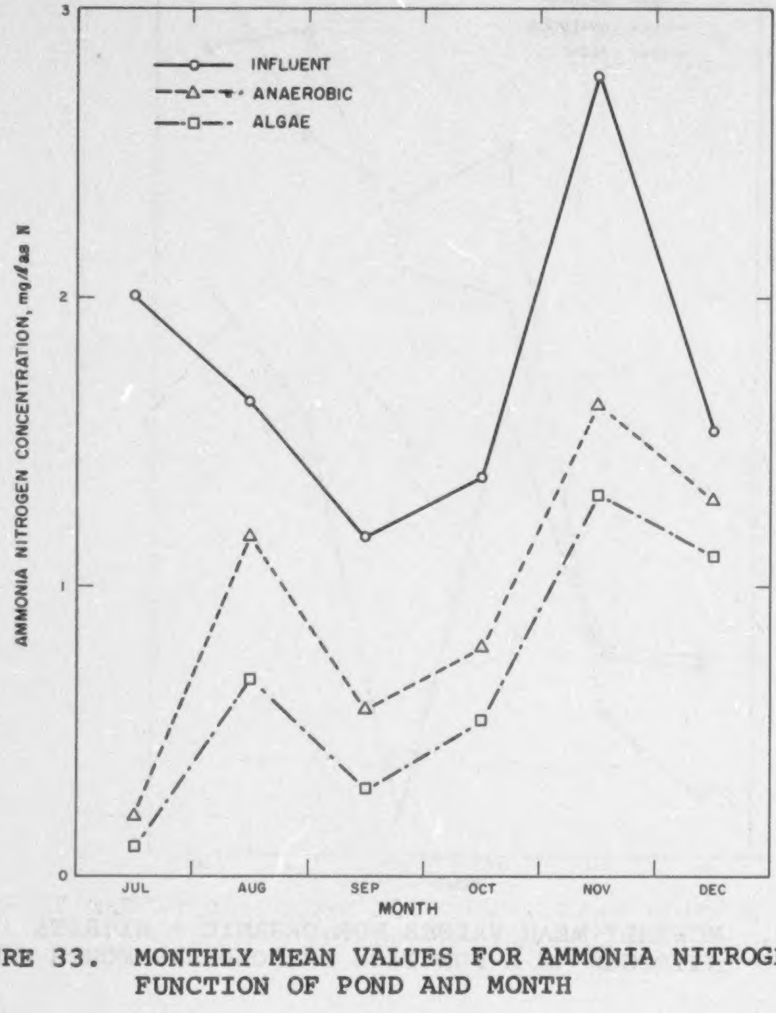

FIGURE 33. MONTHLY MEAN VALUES FOR AMMONIA NITROGEN AS A FUNCTION OF POND AND MONTH

Organic nitrogen was taken as the difference between total nitrogen and the sum of nitrate and ammonia-nitrogen. The concentration involved in this difference could also conceivably involve some nitrite. These differences are plotted in Figure 34. While the data are erratic, it appears evident that the low concentrations of about 2 mg per liter in the influent were greatly increased in the ponds. The increase probably was a result of the accumulation of cellular material which ultimately led to an increase in organic N plus nitrite from about 1 mg per liter to more than 4 mg per liter.

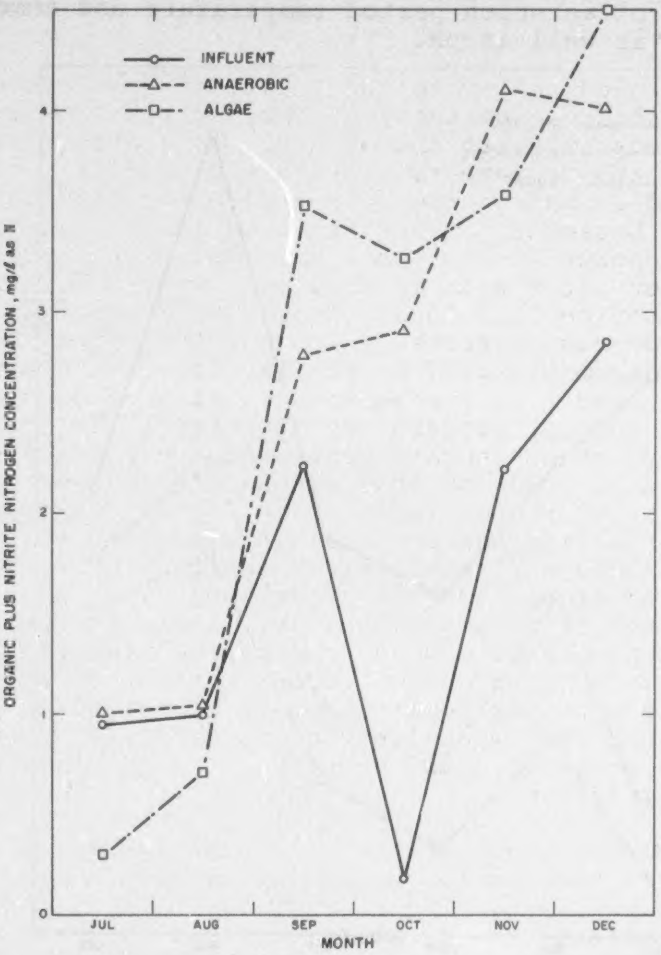

FIGURE 34. MONTHLY MEAN VALUES FOR ORGANIC + NITRITE NITROGEN AS A FUNCTION OF POND AND MONTH

From an overall standpoint, the quantity of nitrogen in the waste was very low when compared with the amount of carbon in the waste. A tabulation of filtered COD, organic carbon, total nitrogen, carbon nitrogen ratios and monthly mean phosphorus concentration is presented in Table 9. Table 9 provides some degree of visualization of nutrient relationships in the system.

If one accepts the concept that organic matter is approaching stability when the carbon nitrogen ratio reaches 10 or less, according to Table 9, stability was never approached in the anaerobic pond and was approached only twice in the algae pond in October and again in December.

It should be noted that with the exception of influent, the phosphorus concentration shown in Table 9 resulted from the addition of phosphorus to the system. As stated earlier, during August and September, phosphate was added to the anaerobic pond as phosphoric acid and during late October, November, and December, it was added to the algae pond. Influent phosphorus without phosphate addition varied from 0 to 4.5 mg per liter with monthly mean values varying from 0.57 in December to 1.53 in November. This quantity of influent phosphorus is probably too low to support high rates of microbial decomposition, especially for high BOD wastes. It should be noted that during the addition of phosphate to the anaerobic pond, phosphate was transferred to the algae pond. However, the phosphate underwent a depletion of some type in the algae pond, so that without direct addition a level of about 0.5 mg per liter prevailed in the algae pond. According to the findings of Zabat (6), and others, this would provide only sufficient P for the growth of about 50 mg per liter of algae. On the other hand, when phosphate was added to the algae pond directly, little phosphate appeared in the anaerobic pond, indicating that it did not remain in solution long enough to be transferred back to the anaerobic pond with the recirculant in any significant quantities. These facts emphasize the concept that in nutrient addition, the point of addition as well as quantity added are highly significant.

Organisms: During the course of the experiments, microscopic observations of the microorganisms in the ponds were made as frequently as possible. The quantities of algae and other organisms were estimated by means of visual microscopic enumeration and by means of packed volume determinations.

The results of the enumerations are tabulated on a daily basis in Appendix G. Appendix G-1 consists of daily algae counts and monthly means of the daily counts. A summary

TABLE 9

Nutrient Relationships

Month	Sample	Filt COD mg/l	C[1] mg/l	N[2] mg/l	C/N	P[3] mg/l
Aug	In	961	404	5.6	72	1.5
	An	217	91	2.6	35	13.9
	Al	112	47	1.8	26	7.3
Sep	In	1128	474	4.8	99	0.78
	An	144	60	3.8	16	2.04
	Al	116	49	4.2	12	1.57
Oct	In	1180	495	4.8	103	0.79
	An	137	57	4.2	14	1.25
	Al	104	44	4.3	10	0.54
Nov	In	1541	647	9.3	70	1.53
	An	209	88	6.2	14	1.43
	Al	150	63	5.4	12	9.30
Dec	In	1969	827	7.5	110	0.57
	An	165	69	5.8	12	0.43
	Al	130	55	6.2	9	7.10

[1] 0.42 x Filt COD

[2] Total Nitrogen in unfiltered samples. No extra nitrogen was added during the course of these experiments.

[3] P was added at the approximate average rate of 5 mg/liter. Because of poor flow control, phosphorus levels were sporadic but in excess of normal requirements.

of these means as a function of pond and month is presented in Figure 35. As is evident from the figure, the mean algae count in the anaerobic pond was about 400,000 per ml and remained fairly constant. The count in the algae pond fluctuated greatly, being relatively low in August, increasing in September, again decreasing in October, and then increasing in November and December. The mean value was approximately 1 x 10^6 cells per ml.

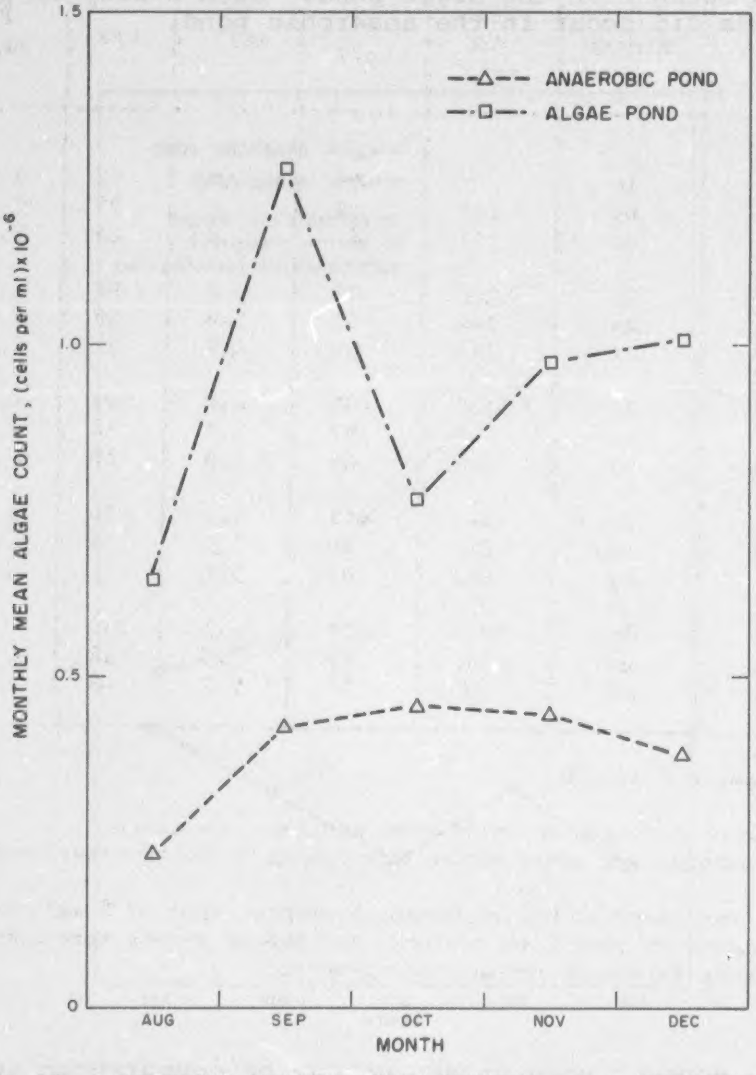

FIGURE 35. MONTHLY MEAN ALGAE COUNTS AS A FUNCTION OF POND AND MONTH

Results of daily determinations of the packed volume of algae cells in terms of ml per liter wet weight are tabulated in Appendix G-2. As noted previously, these volumes were estimated as percentages of the total packed volume of solids. Monthly mean values for the algae volumes are plotted in Figure 36 as a function of pond and month. The pattern for packed volume was roughly the same as that for the algae count, except that no drop in packed solids volume occurred in October in the algae pond. Such a drop in packed solids volume did occur in the anaerobic pond.

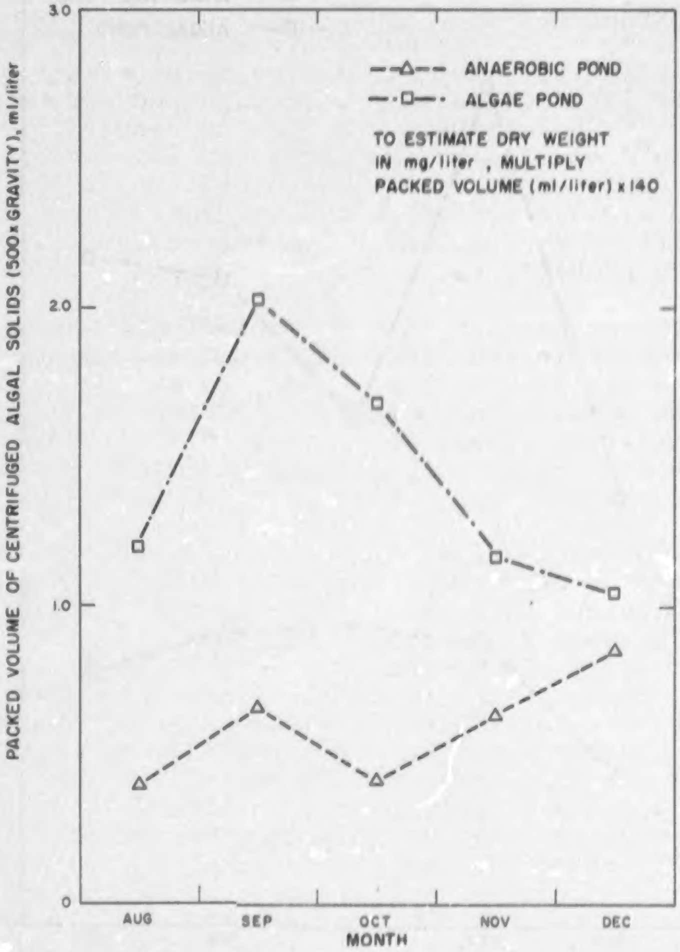

FIGURE 36. MONTHLY MEAN PACKED VOLUME OF CENTRIFUGED ALGAL SOLIDS AS A FUNCTION OF MONTH AND POND

There is a fairly fixed ratio between packed volume of green algae cells in ml per liter and dry weight in mg per liter. As indicated in the note in Figure 36, to estimate dry weight in mg per liter, one should multiply the packed volume of algae in ml per liter by 140. Thus, a packed volume of 2 ml per liter of algae is equivalent to a dry weight of 280 mg per liter of algae. Inasmuch as the organic-N equivalent to this data was only about 3.5 mg per liter, and green algae normally contain a minimum of 6% nitrogen dry weight, the algae were either extremely nitrogen deficient, or the material measured was not entirely green algae. A fixed ratio also exists between the dry weight of algae cells and the amount of oxygen produced as a result of algae growth. The ratio is 1.6 mg of O_2 per mg of algae. Thus, a packed volume of 2 ml of algae per liter indicates that 2 x 1.6 x 140 = 450 mg of O_2 per liter of culture were produced during growth of the algae. If 20 days were required to accomplish such growth, the rate would be 22.5 mg per liter per day, which for a three-foot depth could be equivalent to 200 lbs per acre per day. While algae appeared in the anaerobic pond, they were brought there by recirculant and their growth in the anaerobic pond was probably small due to poor light conditions.

There is little question that the changing numbers and weights of algae present in the ponds in August and October were functions of the proliferation of predators at the expense of algae in the ponds. Two main types of predators invaded the ponds at different times. They reached their peak numbers about two months apart--daphnia and related organisms in August and rotifers in October.

Tabulations of such daily observations as are available for daphnia are presented in Appendix G-3 and the monthly mean values are plotted as a function of pond and month in Figure 37. As indicated by the figure, daphnia were found in the algae pond during all months, but were at their peak concentration in August. Mean concentrations as high as 20 of these relatively large organisms per ml were observed. Because of recirculation, the organisms when abundant, could be found in the anaerobic pond as well as in the aerobic pond, although their numbers were relatively small in the anaerobic pond. Apparently they were unable to survive in the generally anaerobic environment of the anaerobic pond.

Observations of rotifer numbers are tabulated in Appendix G-4 and the monthly mean values are plotted in Figure 38. As is evident from the figure, the number of organisms rose to a peak during October in the algae pond and in the anaerobic pond. Those in the anaerobic pond probably were drawn there with the recirculation stream, but were able to survive

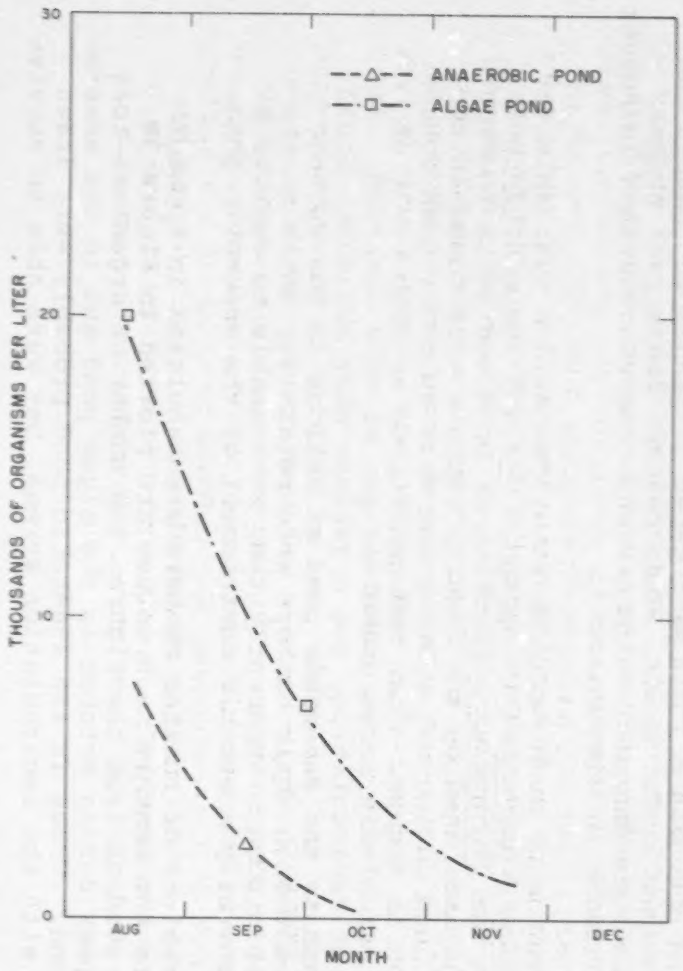

FIGURE 37. OBSERVED DAPHNIA AND DAPHNIA-LIKE ORGANISMS PER LITER AS A FUNCTION OF POND AND MONTH

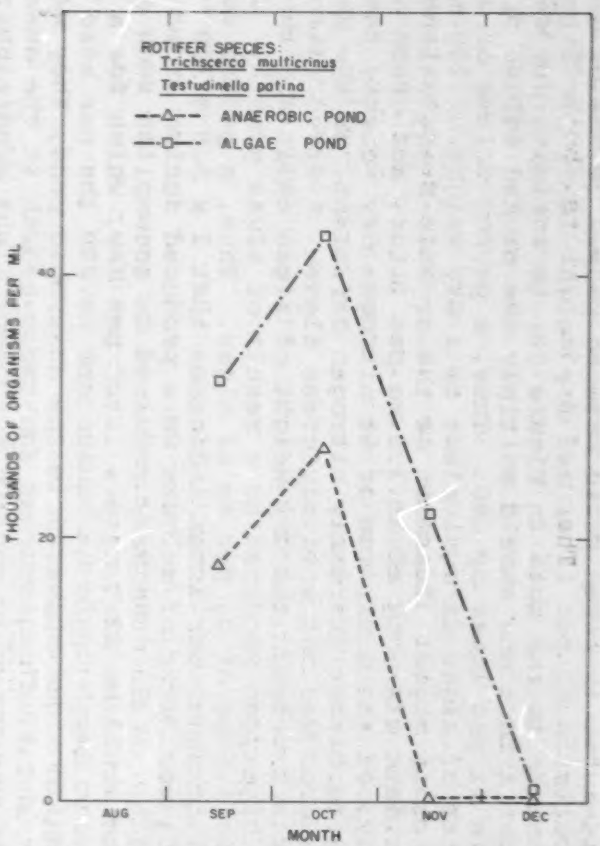

FIGURE 38. MONTHLY MEAN ROTIFER COUNTS AS A FUNCTION OF POND AND DEPTH

in considerable numbers in spite of the low oxygen levels in the anaerobic pond. The decline in numbers, both of rotifers and daphnia during November and December, probably was a result of their sensitivity to lowered temperatures in the ponds. The decline was accompanied by increased numbers of algae. Although it is not apparent from the mean values, daily values indicate that there were several pulses of growth and die-away of the organisms during each month. The pulses of predator growth were accompanied by decreases in algae numbers and volumes, and in the concentration of dissolved oxygen in the algae pond. These details in the daily data are obliterated by taking the mean values over a monthly period.

During September and October, purple sulfur bacteria were visibly prominent in the anaerobic pond, and due to recirculation, were also swept into the algae pond. The data collected on these organisms are tabulated in Appendix G-5 and mean values are plotted as a function of pond and month in Figure 39. As evidenced by the figure and appendix, the thiocystis-like *Thiopedia* and *Chromatium* species attained enormous numbers of organisms (as high as 50 million per ml) and their packed volumes in some cases were almost as great in the anaerobic pond as those for the algae in the algae pond.

Algae types and their occurrence by pond and month are tabulated in Appendix H and a summary of species and occurrence is presented in Table 10. According to the table, 30 species of algae were endemic in the ponds at various times; 19 species occurred in the anaerobic pond; and 29 species occurred in the algae pond. The most frequently observed species in the algae pond in descending order were members of the genera *Chlorella*, *Nitzchia*, *Oscillatoria*, *Scenedesmus*, *Euglena*, *Phacus*, and *Chlorococcum*. With the exception of species of *Chlorococcum*, species of these genera also were predominant in the anaerobic pond. The greatest diversity of species occurred in September in both ponds, with October and August following in descending order.

Gas Production: Daily gas production from the anaerobic pond is tabulated in Appendix G-6 and mean monthly production is plotted in Figure 40 as a function of the mean monthly temperature in the anaerobic pond. As noted previously, because of a lack of time and gas, an intended program of gas analysis could not be initiated and the gas composition was not precisely determined. It was superficially determined by a simple ignition test, to contain a substantial combustible fraction.

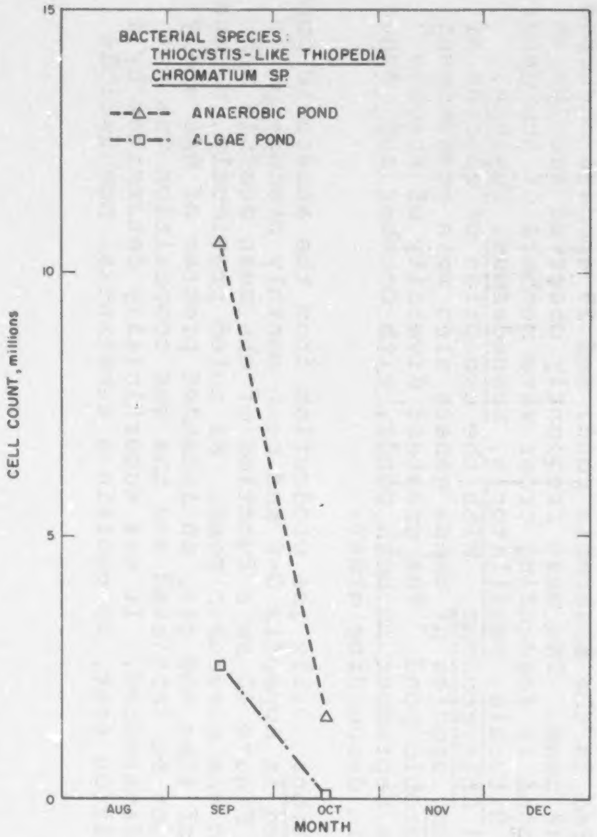

FIGURE 39. MONTHLY MEAN PURPLE SULFUR BACTERIA COUNT AS A FUNCTION OF POND AND MONTH

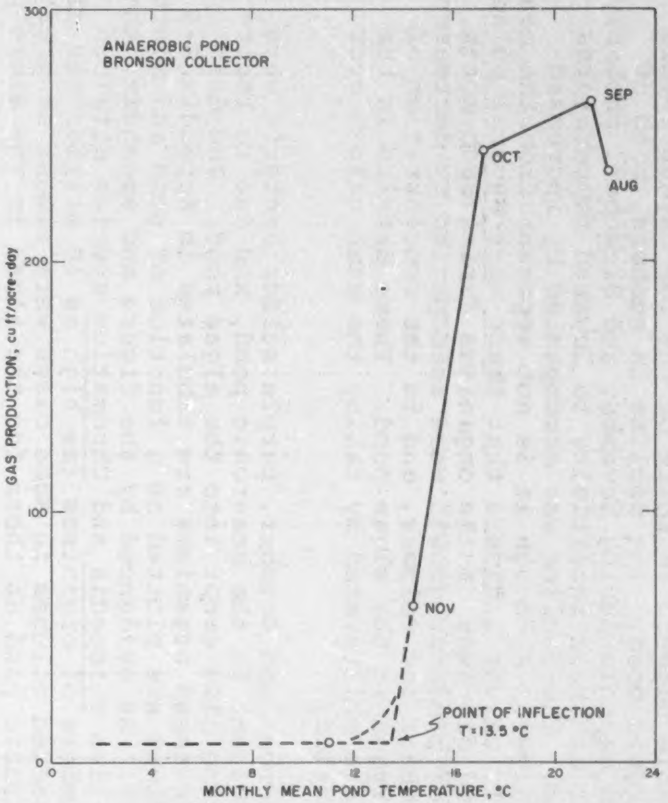

FIGURE 40. RELATIONSHIP BETWEEN GAS PRODUCTION AND TEMPERATURE FOR VARIOUS MONTHS

TABLE 10

Algal Species in the Ponds and the Percentage of Samples Examined in which they Occurred as a Function of Pond and Month

Algal Species Occurrence % of Sample	Anaerobic					Algae				
	Month					Month				
	Aug	Sep	Oct	Nov	Dec	Aug	Sep	Oct	Nov	Dec
Oscillatoria	92	87	86	50	100	92	77	87	60	60
Scenedesmus	74	77	64	50	33	85	91	80	80	80
Chlorococcum	7					11	55	13	40	
Nitzchia	92	96	93	80	33	96	91	87	90	80
Chlorella	100	96	93	100	67	100	91	100	100	80
Euglena	78	73	64	40	33	96	82	80	80	80
Phacus	52	27	29			67	50	33	30	60
Fragilaria						4				
Anabaena	7	9			33	26	36	7		40
Pyrobotrys	30	36				26	18			
Stigeoclonium	26						5			
Actinastrum		55	71	20	33		55	66	30	20
Coelastrum							18	7		
Cyclotella		5	7				14			
Tetraedron		5					14	7		
Closterium		18	7	10			18	13		
Ankistrodesmus		14					23		10	
Selenastrum		5					5			20
Anabaenopsis		5					5			
Diatoma		18	29	10		7	14	53	30	20
Chlorococconeis		36			33		27			
Oocystis							9		10	
Microspora							5			
Gomphosphaeria							9			
Microcystis							14	7		
Stephanodiscus							18			
Palmella							14			
Gomphonema							5			
Staurastrum										
Carteria							5			

As is indicated by the figure, gas production was apparently quite low during August and September. On the other hand, the figure indicates that beginning in October, gas production apparently was severely limited by temperature if not by other factors. A comparison of gas production (Appendix G-6) on a day-to-day basis with temperature in the anaerobic pond (Appendix A-3) indicates that a definite inflection point occurred when the pond temperature reached 13.5°C. Pond temperatures were actually measured near the pond surface, whereas gas emission was primarily from the pond bottom and therefore sensitive to bottom temperature. Although bottom temperature was not measured on November 20, it probably was at least 1.5°C less than that of the water near the surface. Thus, the temperature-gas production relationship described by Bronson _et al_. (7) in which gas production increases linearly with temperature above 15°C is closely approximated by these data.

Nutrient Studies: In the special fertilizer study, 12-liter vessels were operated during November, 1968, by starting with algae pond liquid incubated in laboratory light and pouring off one liter each day and replacing the liquid with "spiked" algae pond effluent. Incubation was at room temperature and illumination was with 30-watt fluorescent lamps. The additions of fertilizing materials consisted of potassium phosphate, ammonium phosphate, ammonium nitrate, sodium nitrate, phosphoric acid, and 15-8-4 commercial fertilizer. An algae pond effluent liquid control was also incubated and monitored for growth. The enrichments were added to provide approximately 5 mg per liter of the fertilizing chemical in the final solution. The systems were initially buffered with 50 ml of sodium carbonate solution which apparently was effective because the pH of all cultures remained between 7.5 and 8.5 during the entire test. Although the test was extended for about 25 days, problems with rotifers and purple sulfur bacteria became overwhelming during the last 10 days of the test. Therefore, the results after 15 days of incubation at room temperature in the light are taken as most representative. These data in terms of packed volume are shown in Table 11. As shown in the table, on the 15th day best growth was found to have taken place in ammonium phosphate, followed by potassium phosphate, ammonium nitrate, commercial fertilizer control, sodium nitrate, and phosphoric acid in the order named. A reference to Table 9 shows that the algae pond effluent averaged 9.2 mg per liter P during November; hence, it is not surprising that phosphorus did little to enhance growth in the control. In view of this, it is somewhat surprising that the addition of potassium phosphate gave such a high assay growth response. The overall results indicate that ammonia and perhaps phosphate are essential fertilizers and that potassium should be reexamined, particularly in view of the fact that as shown in Table 11, at least one sampled beet waste initially contained as much as 88 mg per liter of potassium.

TABLE 11

Nutrient Spiking Experiment

No.	Fertilizer Applied at About 5 Mg Per Liter	pH	15-Day Packed Volume Mg Per Liter
1	Control* Pond 4	7.7	0.6
2	Potassium Phosphate	7.9	2.2
3	Ammonium Phosphate	8.1	4.8
4	Ammonium Nitrate	8.1	2.0
5	Sodium Nitrate	7.9	0.5
6	Phosphoric Acid	8.0	0.5
7	(15-8-4) Commercial Fertilizer	8.0	0.7

*Algae Pond Effluent

SECTION VI

DISCUSSION

The results of this study show very clearly the extensive variations in waste strength, pH, and nutritional characteristics of beet sugar factory wastes. The seasonal variations in waste strength are so large that it would be impossible to design an effective unbuffered, short detention waste treatment system for steady-state or average conditions. The degree of variability is apparent when one examines the unfiltered COD data for influent in Appendix C-1, in which values vary from 550 mg per liter in August to 3643 mg per liter in November, and 3380 mg per liter in December; and when one considers the influent pH values shown in Appendix D-1 in which the variation is from 5.7 to 11.6.

No short-detention period biological system lacking in buffer capacity could withstand sudden shifts in nutrient and pH of the magnitude found without violent upsets or complete failure in essential microbial growth. A circulated algae pond could tolerate the changes in pH, but could not tolerate the changes in loading. Activated sludge units could not tolerate either the change in pH or the change in loading. Trickling filter units could perhaps tolerate the variable loading but could not tolerate the variable pH. Thus, activated sludge units, circulated algae ponds, and trickling filters, if considered in the design of primary units of systems for factory waste would have to be designed for that loading which could not be exceeded at least 95% of the time. They would have to be continuously monitored and protected from changes in pH. Design criteria such as these would make such treatment extremely expensive.

The obvious corollary to these statements is that a massive primary buffer system is vital to any successful and economical biological treatment of beet sugar factory waste. In considering the design characteristics of a buffering system, the anaerobic pond is an obvious choice because its simple earthwork construction, large size and relatively long detention period will, according to our evidence, buffer almost any extreme variation in pH which might occur in a factory effluent and would dampen changes in BOD. At the same time it would be relatively inexpensive.

In view of the necessity of a buffer pond, it is fortunate that in addition to acting as a buffer, a substantial degree of waste treatment is attained in an anaerobic pond.

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It was found during the course of these investigations that in the anaerobic pond BOD removal was directly proportional to BOD loading in the range of 500 to 2,000 lbs of BOD per acre per day. At loadings above 2,000 lbs, removal efficiency is believed to decline. The removals as found are related to loading approximately as follows;

$$R = 0.8\ L \qquad (2)$$

in which L is the ultimate BOD load between 500 and 2,000 lbs per acre per day and R is the ultimate BOD removed. Of course, both R and L should be expressed in the same units. Thus, it appears that an anaerobic pond loaded at 1,000 lbs of ultimate BOD per acre per day will produce an effluent containing 200 lbs of ultimate BOD per acre per day and one loaded at 2,000 lbs of ultimate BOD per acre per day will produce an effluent having 400 lbs of ultimate BOD per acre per day. If BOD loading were the only criterion of performance, the obvious choice of recommended design loading would be 2,000 lbs of ultimate BOD per acre per day. It is an unfortunate fact that when the study pond received BOD loadings as high as 2,000 lbs per acre per day, it was continuously malodorous; hence, some criterion other than Equation 2 is required on which to base a decision regarding an upper limit for anaerobic pond loading. Two main criteria seem to be available: odor level and acceptable discharge BOD.

Inasmuch as odor is one of the most urgent problems, odor level will be discussed first. In the case of the anaerobic pond, the data accumulated during this study were not sufficiently refined for a final conclusion; but from inspection of Figures 24, 25, 26 and 27, one is left with the general impression that for normal beet waste, an odor product of lower than 8 to 10 may be barely acceptable. An odor product much above 10 is definitely unacceptable because it is always accompanied by sulfide concentrations above 0.025 which are always detectable. An allowable odor product of 10 would permit sulfide odors of 2 intensity or foul odors of intensity 1.7 some of the time. However, such low intensities would imply very little carrying power for the odors; or in air, odors of such intensity would be quickly diluted to subliminal levels as a function of distance from the ponding site. It seems quite certain that odor products of 8 or less would be acceptable for anaerobic ponds because these levels were frequently reported for the algae pond, which rarely had a high odor product in laboratory samples and was never described as objectionable in pond-side observations.

In the plot of odor product vs loading, there appears to be a straight-line relationship with two observed exceptions--

the October 1967 data and the November 1968 data. These data come from periods when there were serious interruptions in flow, and consequently, rapid changes in the environment. Total nitrogen concentrations were also high during these periods, possibly due to the discharge of Steffens waste. Steffens waste is, of course, notorious for its ability to produce vile odors when impounded, and "Steffens waste spills" are always accompanied by sudden increases in odor in ponding systems. There was, however, no reported incidence of a "spill" and no report that Steffens waste had been bled into the effluent. Thus, it can only be concluded at this time that a load of 1,000 lbs of ultimate BOD per acre per day may be acceptable in an anaerobic pond when mechanical surface aeration is applied to the extent of meeting one-third of the applied BOD, and when the effluent is discharged into a functional aerobic or algae pond from which there is a recycle of about 1 Q and in which algae are growing and producing oxygen.

With regard to acceptable discharge BOD, effluents from the anaerobic pond varied from 120 mg per liter at a load of 500 lbs per acre per day to in excess of 400 mg per liter at a load of 2,000 lbs per acre per day. Water of this quality would be useless and its discharge illegal without extensive additional treatment.

The additional treatment studied involved both facultative and algae ponding. At BOD levels ranging from 50 to 200 lbs per acre per day as noted previously, odor products in the systems studied tended to be 6 or less and objectionable odors at the pond side were minimal.

With regard to the application of BOD criteria to the facultative pond and algae pond, an examination of the available data is best aided by plotting mean final effluent BOD as a function of mean BOD loading. Such a plot is shown in Figure 41. As is evident from the figure, the BOD of unfiltered effluents was not affected by loadings up to 100 lbs per acre per day while the BOD of filtered effluents was not affected by loadings up to 180 lbs per acre per day, but the unfiltered BOD both from the facultative pond in 1967 and the algae pond in 1968, would not be acceptable in the average aquatic environment under the currently proposed water quality standards (8).

It is important to note that decreased BOD loadings below 100 lbs per acre per day did not appear to influence the effluent BOD, probably because most of the BOD involved in these samples was of a suspended nature, either in the form of colloidal sulfides, algae cells, or of bacterial cells. This was true because the algae pond was continuously mechanically mixed and samples were drawn directly from the mixing system. The suspended nature of the BOD is demonstrated by the fact that the BOD of the algae pond effluent was reduced from levels of 150 to 190 mg per liter to 10 to 13 mg per liter by filtration. In view of these relationships, it is apparent that the residual BOD in the algae pond effluent was due to BOD which could have been removed. Therefore, had the removal been effected, obviously greater efficiencies would have been attained.

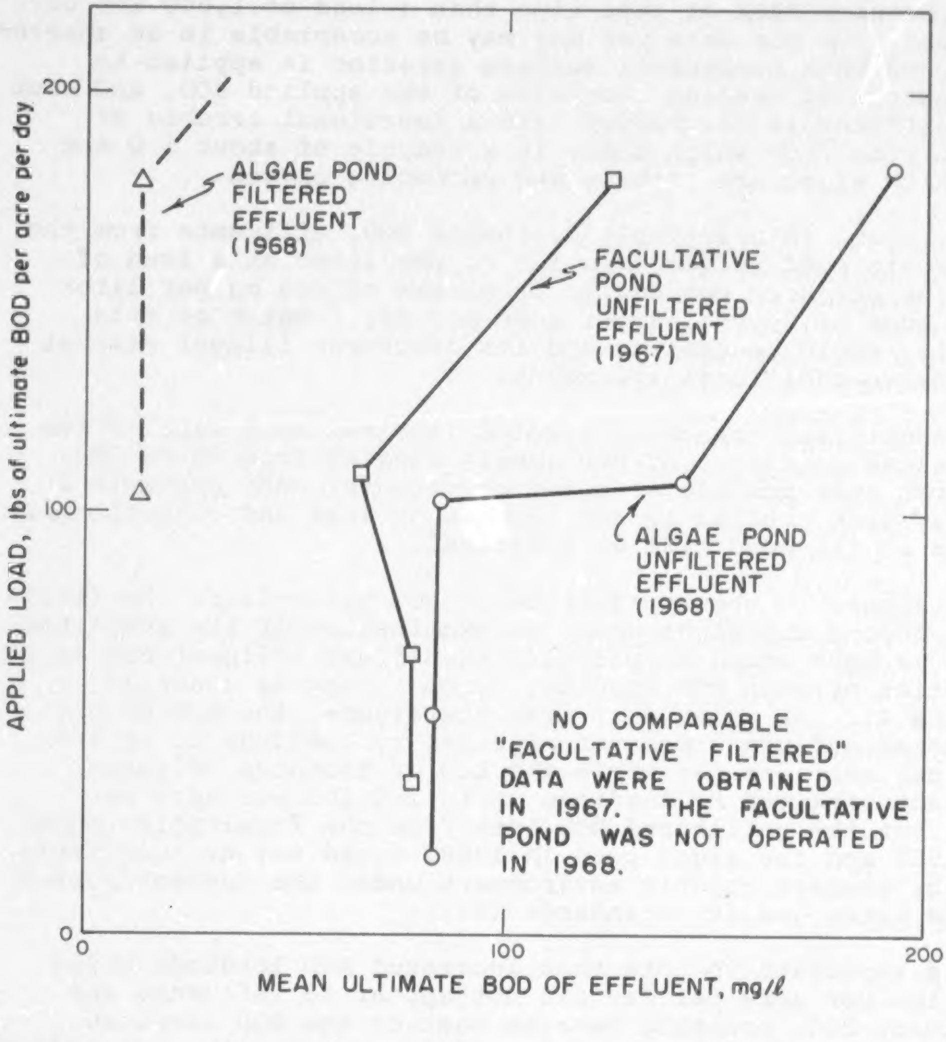

FIGURE 41. MONTHLY MEAN BOD OF ALGAE OR FACULTATIVE PONDS AS A FUNCTION OF BOD AND FILTRATION

Merely decreasing the BOD loading below 100 lbs per acre per day did nothing to improve effluent quality. On the other hand, filtration improved effluent quality dramatically, even at loadings of 180 lbs per acre per day. An examination of suspended solids data shows that effluent suspended solids often exceeded a concentration of 500 mg per liter with over 75% volatile matter. Thus, apparently an improved unfiltered effluent could not be attained by reduced loading. It should be noted, however, that in the case of the algae pond, loadings between 100 and 180 lbs per acre per day yielded effluents which when unfiltered had BOD levels between 80 and 190 mg per liter respectively. Thus, while a loading of 100 lbs per acre per day was associated with unsuitable effluents, higher loadings produced effluents substantially more unsuitable. The apparent conclusion is that aerated-anaerobic ponding followed by either facultative or algae ponding without further treatment did not produce an effluent suitable for discharge, regardless of the degree to which loading is decreased. Aside from the alternative of intensive mechanical aeration (which will treat, but not dispose of water), one is confronted with only two clear alternatives for complete disposal: 1) to use facultative secondary ponds loaded at 100 lbs per acre per day or less and to dispose of the final effluent on land owned by the Factory from which there is no discharge; or 2) to use a more intensive form of secondary ponding and to remove suspended solids from final effluents prior to discharge by filtration or some other method of separation which will remove the fine suspended solids which contribute most of the effluent BOD. The discharge of filtered facultative pond effluent is another possible alternative, but no study was made of facultative pond effluents which had been filtered.

Intensive secondary ponding could involve the use of mixed algae ponds of the type studied, or an even more intensive form of algae production. For example, where climate permitted, the algae pond could be optimized for photosynthetic oxygenation with an average production of about 200 lbs of oxygen and 120 lbs of algae per acre per day. Under these conditions, it is conceivable that the value of the filtered solids could pay for the cost of filtration. However, this would require much more study. Allowable loading would then be about 200 lbs per acre per day, and following separation, the discharge would meet rigorous quality standards. One may then logically say, "Why discharge such high quality water, particularly in water-short areas?" If the quality of a filtered discharge is high as indicated in Figure 41, reuse in the factory by recycle is a worthwhile consideration whenever filtration is used. Obviously, the less new water brought into a factory, the less it will have to discharge. On the other hand, because of the high water content of beets, it seems inevitable that factories will always be forced to discharge or otherwise dispose of large amounts of excess water regardless of recovery practice.

Based on the criteria of 80% BOD removal in a primary anaerobic pond and a loading of 200 lbs BOD per acre per day in an algae pond, one can explore the areal requirements for treatment in an idealized anaerobic-algae system. To have a basis for calculation, a 4.5-K ton factory discharging 36,000 lbs of BOD per day is assumed. It is also assumed that excessive odors will occur when the aerated-anaerobic pond loading exceeds 1,000 lbs of BOD per acre per day. If a load of 500 lbs of BOD were applied to the anaerobic pond, the area of anaerobic pond would be 72 acres, the discharge would be 100 lbs per acre per day or 7,200 lbs, and 36 acres of algae pond would be required for an aggregate area of 108 acres. If a load of 1,000 lbs per acre is applied to the anaerobic pond, the total loading of 36,000 lbs will require 36 acres. The anaerobic pond effluent will contain 7,200 lbs of BOD and therefore will require 37 acres of algae pond. The aggregate area in this second case would be 72 acres. If a load of 2,000 lbs of BOD per acre were used, 18 acres of anaerobic pond would be required for anaerobic treatment, but odors would be severe and a stronger waste would be discharged to the algae pond. Although according to Equation 2 the effluent BOD would be 7,200 lbs, and would require 36 acres of algae pond, in reality, because of bacterial and sulfide turbidity, an area larger than 36 acres--say 40 acres--probably would be required if the effluent were to be fully oxidized. Moreover, strong odors would occur.

A plot of these relationships is presented in Figure 42. From the figure, it becomes evident that with the assumptions described, the minimum area required for odor-free treatment of factory waste from a 4.5-K ton factory by an aerated anaerobic-algae system would be about 72 acres. Higher loadings would be accompanied by severe odors and, as indicated by the dotted portion of the top curve, would require more algae ponds for aeration. Lower loadings would, of course, require more area, the area increasing as the areal loading is decreased.

As an alternative to using facultative or algae ponding as the secondary system, one should consider the alternatives of more intensive aeration of primary ponds or the use of aerated secondary ponds. The possibility of applying additional surface aeration in an anaerobic pond to prevent odors and to permit higher areal loadings and decreased pond surface area is worthy of consideration, and was to some extent examined experimentally. In the study with a 5 HP floating surface aerator, it was found that as long as the dissolved

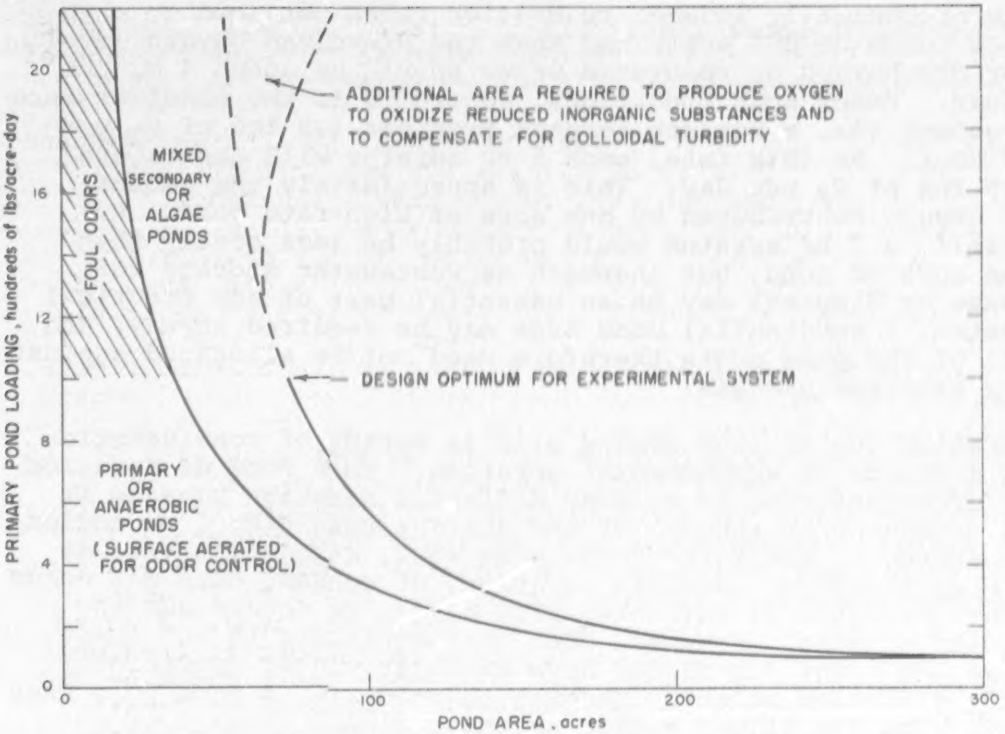

FIGURE 42. MAIN WASTE PONDING AREA REQUIRED FOR 4.5 K TON FACTORY

oxygen remained zero, oxygen entered the pond at the rate of 307 lbs per day due to the 5 HP aerator. Odor emission, however, appeared to be a function of the amount of unoxidized material remaining, rather than a function of the rate of aeration. Thus, if one were to go from a loading of 1,000 lbs per acre per day to a double loading of 2,000 lbs per acre per day, control of odor probably could not be attained by aerating at twice the 307 lbs per acre per day, i.e., 614 lbs per acre per day. Instead, aeration would have to be at a rate of 1,000 + 307 lbs or 1,307 lbs per acre per day. Thus, it is believed that to double loadings in the system studied, aeration would have to be increased fourfold to prevent odors. The savings in area would thus have to be evaluated in terms of the cost of one 20-HP aerator operating continuously for each acre of secondary pond replaced. Thus, the possibility of decreasing area by going to loadings higher than 1,000 lbs per acre per day is not as attractive as it might at first seem.

With regard to replacement of secondary facultative or algae ponds with aerated secondary ponds, it will be assumed that the mechanically induced reaeration rates obtained in oxygen-free ponds do not apply and that the dissolved oxygen level for discharged or recovered water should be about 4 mg per liter. Under such conditions, according to the manufacturers brochure (5), a surface aerator provides 1.8 lbs of 0_2 per HP hour. At this rate, each 5 HP aerator will contribute 220 lbs of 0_2 per day. This is approximately the amount of oxygen contributed by one acre of high-rate pond. By itself, a 5 HP aerator would probably be less costly than one acre of pond, but inasmuch as wastewater storage for reuse or disposal may be an essential part of any practical system, a substantial pond area may be required anyway, and all of the pond costs therefore need not be allocated against the aeration process.

Aeration due to flow mixing also is worthy of consideration as a source of supplemental aeration. This form of aeration is often referred to as eddy diffusion aeration because it is dependent on renewal of the surface resulting from eddies generated as the water moves past small discontinuities at the pond bottom. Surface aeration, of course, does not occur when the water is saturated with oxygen as occurs due to photosynthesis. However, when photosynthesis is not operative (at night, on cloudy days or under winter conditions), eddy diffusion aeration becomes functional. A pond four feet deep with the liquid moving around a closed circuit at a velocity of one foot per second and containing no free dissolved oxygen will require about 50 HP hours per acre and absorb about 100 lbs of oxygen per acre per day through surface aeration. Although this amount of oxygen is small compared with that attainable through mechanical surface aeration, it is a method which is compatable with photosynthetic oxygenation. If the liquid contains growing algae and essential nutrients, the algae may produce over 200 lbs of oxygen per acre per day through photosynthesis, and the dissolved oxygen level will always be positive and frequently near saturation. Oxygen produced photosynthetically, of course, does not depend upon an oxygen deficit for input; and hence, never is accompanied by vile odors. Odors could result if the pond were so severely overloaded on a sustained basis that algae were unable to grow. However, if algae either fail to grow for one reason or another or are killed by toxins or predators, eddy diffusion aeration in the flow system will provide for the absorption of sufficient oxygen by the pond to keep it from producing vile odors of high intensity, providing the loading does not exceed 200 lbs per acre per day. Thus, flow mixing is an excellent backup for photosynthetic oxygenation; but it is not as efficient an aeration system as is mechanical surface aeration.

Provision for any form of biological treatment requires in addition to a mild and stable environment, adequate nutritional conditions. Flume water usually contains about 400 mg per liter of carbon as C, about 15 mg per liter of available nitrogen as N, and about 3 mg per liter of soluble phosphate as P. Rapidly growing bacteria are about 40% carbon as C, 10% nitrogen as N, and 1.5% phosphorus as P, and radidly growing microalgae are about 55% carbon as C, 8% nitrogen as N, and 1% phosphorus as P. Based on these percentages, flume water contains enough carbon to support 725 mg per liter of algae, enough nitrogen to support 188 mg per liter of algae, and enough phosphorus to support 300 mg per liter of algae. It is clear that compared with carbon, there is a deficit in both nitrogen and phosphorus, and that 725/188 x 15 or about 88 mg per liter of N and 725/300 x 3 or about 7.25 mg per liter of P would be required to permit incorporation of all of the organic carbon into algae. Thus, 73 mg per liter of N and 4.25 mg per liter of P would have to be added. A less expensive alternative would be to remove carbon by processes other than by photosynthesis, and thereby decrease the carbon to a point at which it is in balance with the nitrogen and phosphorus for algae growth. By so doing, it would not be necessary to provide supplementary nitrogen and phosphorus.

Several processes observed in the anaerobic pond during this study are accompanied by loss of considerable carbon dioxide to the atmosphere. This is probably especially true in the case of mechanically aerated ponds. For example, the satisfaction of 307 lbs of BOD per acre each day by aeration theoretically led to the evolution of 450 lbs of CO_2 per acre. Thus, probably 122 lbs of carbon per acre per day was lost to the air. This alone would constitute a loss of 222 lbs of carbonaceous AGP. Following this line of reasoning, if two-thirds of the BOD had been met by aeration, sufficient carbon would have been lost to permit the balance to be incorporated in algae with no need to add nitrogen or phosphorus.

Methane fermentation also is a potential method for decreasing the carbon content of the waste. As noted earlier, gas production in the system was extremely low, and did not establish itself appreciably in spite of the presence of large amounts of carbon, highly anaerobic conditions, adequate temperatures, and sustained periods of inundation. Under the warmest temperatures encountered in the study, 250 ft^3 of gas per acre per day were emitted from the bottom of the anaerobic pond. Although analyses were not made, judging from past experience (7) this gas probably contained about 50% methane, of which 75% is carbon. Thus, for the one acre pond, only about 4 lbs of carbon were lost daily by fermentation. If methane production rates equal to those in domestic sewage ponds had been attained, as much as 200 lbs per acre of carbon would have been lost daily in the form of methane. However, this did not occur in the system. As to why it did not occur, it is possible that methane bacteria found it difficult to survive in a pond in which surface aeration was in progress. However, even before the aerator was installed, as noted in Progress Report III (1), there was a dearth of fermentation. Thus, further studies would be required to substantiate aeration interference. Another hypothesis advanced for poor fermentation is the excess of H_2S or sulfides in the system due to vigorous sulfate reduction in the anaerobic pond as discussed under Chemical Changes. Sulfide is known to be toxic to methane bacteria even in moderate concentrations. Thus, carbon elimination by methane fermentation could have been inhibited by this mechanism.

In order to continue with the discussion of carbon, nitrogen, and phosphorus ratio and the need for nutrient supplementation, it is necessary to digress slightly to explore sulfate reduction in some detail, since this is also a potentially significant way in which carbon may be lost.

The overall reaction involved in production of H_2S from sulfate using organic matter as an energy source is approximately:

$$H_2SO_4 + 2CH_2O \xrightarrow[\text{Organics}]{\text{Bacteria}} H_2S + 2CO_2 + H_2O \quad (3)$$

According to the data on sulfate reduction shown in Figure 21, as much as 208 mg per liter (average about 140 mg per liter) of sulfate was reduced in the anaerobic pond during the five-month period of observation. Based on the stoichiochemistry of equation (3), the reduction of 140 mg per liter of sulfate would have involved the oxidation of 88 mg per liter of organic matter and the production of 50 mg per liter of H_2S and 128 mg per liter of CO_2 or 35 mg per liter of carbon. A substantial fraction of this CO_2 was doubtlessly incorporated in the alkalinity of the water in the anaerobic pond.

One may question why that although 50 mg per liter of H_2S were produced, a maximum of only 5-6 mg per liter of HS^- were recovered. This imbalance may be explained by the supposition that as soon as HS^- was produced, it could have reacted in several ways. It could have reacted with magnesium or other metals in the system to produce insoluble metal sulfides which of course were not measured in the dissolved sulfide determination; it could have been utilized by sulfur bacteria. Emission into the air was evidenced by the presence of sulfide odors about the anaerobic pond. However, the magnitude of emission must have been small because at the pH of 7.5 to 8 (a level almost always found in the anaerobic pond), most of the sulfide would be present as the HS^- species rather than as H_2S.

Inasmuch as there is no H_2S normally in the air, the reaction involved in the emission of H_2S occurs spontaneously whenever dissolved H_2S exists in solution. The quantity remaining in solution is mainly a function of pH. The reaction is:

$$H^+ + HS^- \xleftrightarrow[\text{Basic}]{\text{Acid}} H_2S\uparrow \qquad (4)$$

At pH 4 practically all of the material is in the H_2S or gaseous form and emission rates are high. At pH 6, half is in the gaseous form and half in the ionic HS^- form; and at pH 7.5, about 90% is in the ionic form and 10% in gaseous form and emission rates are low. At pH 9.5, almost all material is in the ionic form and there is no emission of H_2S. Thus, in view of the pH levels in the anaerobic pond (cf. Figure 10), the possibility is slight that all H_2S would have been emitted due to aeration during August, September, October, and November when the pH was higher. Yet, a substantial fraction could have been lost that way during December when the pH was low. The curves in Figure 21 give evidence that some sulfides were probably carried over into the algae pond as a reduced complex which later was oxidized to sulfate. This is evidenced by the fact that the sulfate concentraion in the algae pond was consistently greater than it was in the anaerobic pond.

With regard to the loss of sulfide to sulfur bacteria, according to the data in Appendix G-5, there were numerous sulfur bacteria in the pond from time to time although their biomass was small. However, several parts per million of sulfide could have been converted to elemental sulfur by these bacteria.

Returning to the specific question of carbon losses, according to Equation 3, the overall conversion of carbon due to sulfate reduction must have been on the order of 128 mg per liter as CO_2 or 35 mg per liter as carbon. Overall then, more than one-half of the carbon introduced must have been converted to CO_2.

Another check on carbon transformation is provided by the COD data. According to COD information (see Table 5), the overall reduction in unfiltered COD for the anaerobic pond averaged 1,150 mg per liter. Based on the classical oxidation equation:

$$CH_2O + O_2 \longrightarrow CO_2 + H_2O \quad (5)$$

For which the combining weights are:

$$30 + 32 \longrightarrow 12 + 32 + 18$$

An average carbon release of 460 mg per liter in the anaerobic pond would have occurred due to oxidation of 1,150 mg per liter of COD. It cannot be decisively stated, however, that the decreases in organic carbon was accompanied by an increase in alkalinity, because the alkalinity was not measured routinely. If an actual loss in carbon occurred, and if nitrogen and phosphate had remained constant while carbon decreased, there would theoretically have been nearly sufficient N and P to satisfy the carbonaceous algae growth potential of liquid entering the algae pond. Even though carbon may have been lost, nitrogen as well as carbon and sulfate was also lost as the carbon was passed through the anaerobic system. The greatest loss occurred in nitrate-nitrogen. Losses in this nitrogen form were as high as 90%. Losses in ammonia-nitrogen also amounted to from 20% to 90% or more of that originally introduced, depending on the time of year. Inasmuch as there was so little nitrogen to begin with, proportional losses in nitrogen kept pace with or exceeded losses in carbon, with the result that a severe shortage of available nitrogen prevailed throughout the series, i.e., in both the anaerobic and the algae pond. Based on the results, the significant conclusion is that it would be difficult to amplify the quantity of nitrogen in the algae portion of the system by adding nitrate or ammonia to the anaerobic pond because they are apparently simply reduced or oxidized and emitted as nitrogen gas or ammonia from the anaerobic pond and thus wasted. With regard to the algae pond, N-fertilization is best accomplished by adding nitrogen to the algae pond directly. The best nitrogen additive to the anaerobic pond probably would be organic N. Organic N addition is potentially provided by settled algae brought in with recirculant and algae pond effluent.

When the applied BOD to the algae pond is 200 mg per liter, 10 to 15 mg per liter of NH_3-N should be adequate to provide for the nitrogen deficiency in the anaerobic pond effluent going to the algae pond. Addition of the nitrogen as anhydrous ammonia probably is to be preferred to adding the nitrogen as nitrate since nitrate would be quickly reduced.

In the past, nitrate has been added to sour anaerobic ponds to provide some degree of odor control. However, because of the large amount of nitrate which must be added to provide control (40% of the BOD) and its costs, this method of controlling odors would be about 5 times as expensive as would be control with floating surface aerators.

Phosphate added to the anaerobic pond and algae pond evidently was accompanied by its rapid disappearance from the system--probably as a precipitate in the algae pond and possibly by phosphate reduction in the anaerobic pond. According to Waksman and Starkey (9), under anaerobic conditions when organic matter and when phosphates and the necessary bacteria are present, phosphates are reduced to phosphate (H_3PO_3), hypophosphites (H_3PO_2), and phosphine (PH_3) gas with the release of CO_2. Thus, nitrates, sulfates, and phosphates are all potentially reduced in anaerobic ponds.

Although the methodology of nutrient addition was not exhaustively explored in this study, the prior discussion is convincing evidence that the strategy of nutrient addition is at least as important as the nutrient addition itself. On the basis of the limited experience obtained in this study, it is certain that nutrient addition could best be studied in a full-scale system.

The question of why algal or facultative ponds following anaerobic ponds and without filtration performed poorly in BOD removal is explained on the basis of several facts derived from the study. First of all, because of the efficiency of BOD removal in the anaerobic pond, only a limited amount of relatively stable BOD remained to be removed in the secondary ponds. Secondly, nitrogen losses in the anaerobic pond limited subsequent algae growth; and finally, the presence of large amounts of colloidal suspended solids in the algae and facultative pond effluent imparted to them a BOD of about 100 mg per liter even when the loading was very low. Had there been separation of suspended solids from the final effluents from the secondary ponds of each system, removals would have been greatly improved.

The greatest difficulties in this series of experiments and in the entire study resulted from the fact that the pilot plant was on a shunt from the main factory waste, and consequently was subjected to very frequent failures in the feed system. Inability to control this factor within the budget provided for the study ultimately led to the termination of the studies, and to the conclusion by the authors that any further pilot work with beet sugar wastes should be done with the entire output of a factory rather than with a shunt system.

The fact that nitrogen and perhaps phosphate usually must be added to flume water for aerobic treatment following passage through an anaerobic pond, and the fact that federal and local standards may be established regulating the quantities of nitrogen and phosphorus which may be discharged into the environment suggests that future studies must involve the control of nutrient additions to give maximum benefit with minimum residual discharge.

Control of effluent BOD as well as effluent nitrogen and phosphorus will almost certainly involve a filtration, coagulation, or separation step to remove suspended solids from final effluents. The development of adequate filtration or harvesting systems is thus an area of significant concern which must be further explored. Effective separation following adequate treatment should permit significant reuse of water for relatively high purposes within a factory.

Predators were extremely difficult to deal with in the algae pond but it is not clear whether the same succession of predators would occur in an algae pond in which there was sufficient nitrogen for algae growth, and hence, in which carbon is limiting. Results obtained in recent studies of domestic sewage systems give some evidence that certain predators such as daphnia cannot withstand the pH changes which occur in carbon-limited algae ponds. Because of their relatively large physical size as compared to algae, predators can be removed from recycled streams by screening. DSM or rotary screens having mesh openings about 200 to 400 microns are effective in predator removal. Both screening and carbon limitation in preference to use of pesticides should be further studied for predator control.

There is no clear explanation for the lack of methane fermentation in the system studied, because as opposed to the findings in this pilot study, methane fermentation is frequently observed in primary beet waste ponds. General observations indicate, however, that the fermentaiion is most active and visible in those ponds which receive a substantial quantity of mud. Whether this mud traps the gas and, hence causes the release of larger and more spectacular bubbles, or whether it actually acts as an essential substrate surface for methane bacteria is not clear. Because primary sedimentation was used, little mud entered the anaerobic pond of this system. Methane fermentation is always slow to start in new systems. Yet there were periods during earlier runs of this series when the ponds showed some evidence of fermentation more vigorous than that observed during the fall 1968 campaign. Studies of a pond in which methane fermentation is definitely established and in which the amount of settleable solids introduced can be controlled would be required to explore this phenomenon.

The pertinence of these studies to cold climate installations should be considered. Chemical treatment with lime for pH control and sedimentation with recycling water, and discharge of excess water to an aerated-anaerobic pond is the only alternative thus far explored (10). This system leads to accumulation of a high carbonaceous load in the recycled water. The maintenance of a high pH causes precipitation and removal of essential nutrients for microbial growth. Thus, decomposition in the anaerobic pond is slow and unbalanced. It is believed that if covered digestion ponds could be developed, it would be preferable to pass wastes through an anaerobic pond prior to chemical treatment. Floating covers for the ponds would preserve factory heat, prevent odors, and permit a high degree of fermentation to occur. Following this fermentation, chemical treatment with supplementary aeration could be applied, and supernatant liquids would be suitable for reuse in the factory or for storage without odor nuisance. Thus, the development of inexpensive pond covers would be a worthwhile study for future investigation.

SECTION VII

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SECTION VIII

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SECTION IX

GLOSSARY

algal centrifuged solids - algae removable by centrifuging at 500 x gravity for 10 minutes.

campaign - (French) the period or periods of a year during which the sugarbeet factory produces sugar.

flume water waste - the transporting and cleansing water for sugarbeets prior to processing. The waste will be high in suspended organic particles, soil, and dissolved solids.

photosynthetic oxygenation - the net surface oxygen production process from algae in aerobic ponds (gross photosynthesis less respiration).

Steffen waste - the waste from a process of treating molasses to produce a precipitate containing sucrose which is then treated to release free sucrose in solution. This waste may or may not be discharged into the flume water.

SECTION X

APPENDICES

APPENDIX A

Environmental Factors

A-1 Sunlight Energy in the Visible Spectrum

A-2 Waste and Pond Water Temperature

A-3 Minimum and Maximum Air Temperature

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APPENDIX A-1

Visible Solar Energy Cal/cm^2 x 10^{-2}

Day	Jul	Aug	Sep	Oct	Nov	Dec
1		2.58		--	0.75	0.27
2		3.24	2.50	0.70	0.55	0.27
3		2.88		1.31	0.58	0.27
4		2.22	2.50	1.31	0.58	0.89
5		2.83	2.41	0.97	1.02	0.86
6		--	2.23	1.71	0.36	0.75
7		1.81	2.20	1.71	1.51	1.02
8		--		1.30	0.87	0.32
9		2.74	2.17	1.70	0.98	0.35
10		--	2.20	1.26	0.87	--
11		--	2.30	1.24	0.87	0.26
12		2.87	2.30	1.46	1.21	0.47
13		2.40	2.37	0.88	1.21	0.37
14		2.40		0.83	0.29	0.30
15		2.24		0.84	0.23	0.42
16		2.57	2.10	0.80	0.67	0.42
17		2.91	1.92	1.21		0.77
18		--	1.92	1.49	0.32	--
19		2.26	--	1.45	0.47	0.78
20		--	1.74	1.55	0.93	0.88
21		--		1.55	0.23	0.65
22		2.15	1.72	1.58	0.12	--
23		2.15	1.72	0.88	0.48	0.52
24		1.56	1.72	0.19	0.46	0.07
25		--	1.72	0.11	0.43	--
26		--	2.25	0.03	1.30	0.26
27		2.47	2.25	0.59	0.55	0.63
28		2.48	1.85	0.59	0.61	0.22
29		2.77	1.85	0.01	0.61	--
30		2.49	--	0.40	0.80	0.30
31	2.83	1.56	2.00	0.13	0.80	0.18
Mean	2.83	2.44	2.07	0.99	0.69	0.48

APPENDIX A-2

Daily Minimum and Maximun Air Temperatures - Tracy
Degrees Farenheit

Day	Aug		Sep		Oct		Nov		Dec	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
1	63	98	59	93	59	75	44	84	33	56
2	62	95	60	96	52	80	58	81	29	58
3	61	100	69	94	46	73	46	81	35	50
4	64	98	69	93	49	77	50	71	42	65
5	63	96	61	90	51	72	57	68	45	58
6	58	92	65	95	47	78	48	74	32	52
7	60	96	63	88	45	82	46	77	41	56
8	63	96	52	85	46	85	48	74	31	56
9	58	92	62	89	57	89	55	69	34	55
10	60	96	62	88	58	86	51	74	31	57
11	63	102	62	88	50	87	44	67	28	52
12	60	102	59	95	68	87	51	66	26	53
13	69	104	67	95	50	88	55	62	33	48
14	69	105	59	92	62	84	57	71	30	50
15	70	104	57	90	51	81	49	68	28	53
16	65	102	59	82	48	86	50	74	24	47
17	68	106	66	80	49	87	54	77	31	50
18	67	107	62	86	49	88	54	68	35	50
19	72	103	54	89	48	84	45	62		
20	60	95	57	95	47	83	48	66		
21	59	99	60	90	52	73	44	70		
22	64	99	62	81	60	77	45	67		
23	60	99	56	83	57	78	36	57		
24	71	98	61	84	47	79	36	56		
25	72	100	59	90	51	81	35	61		
26	67	99	58	92	50	79	36	61		
27	66	96	60	91	46	81	28	61		
28	61	84	57	89	60	75	21	51		
29	57	96	55	85	56	77	35	57		
30	59	100	59	78	44	78	28	55		
31	64	91		--	43	81		--		
[illegible]	62	98	60	89	52	81	45	68	33	54
Ave °C	17	37	16	32	11	27	7	20	1	12

APPENDIX A-3

Waste Temperature and Surface Pond Temperature

Day	Aug			Sep			Oct			Nov			Dec		
	In*	An*	Al*	In	An	Al	In	An	Al	In	An	Al	In	An	Al
1	35.5	23	21	--	--	--	32	17	17	--	--	--	--	--	--
2	35.5	22	20	33	22	23	32	17	17	30	15	15	--	11	9
3	--	21	20	34	24	21	--	18	18	--	--	--	--	10	7
4	--	--	--	33	23	21	--	17	18	--	17	15	--	11.5	8.5
5	23	22	20	--	23	21	26	21	20	--	17	16	--	10	8
6	37	21	20	--	23	22	--	--	--	--	15	17	30	10	9
7	--	21	20	35	23	22	--	17	16	29	17	15	28	10	9
8	--	23	24	--	--	--	--	--	--	28.5	15.5	14	--	--	--
9	29	24	23	34	23	20	31.7	22	15	29	17.5	18	29	12	12
10	38	23	22	33	22	19	31.1	15	16	--	--	--	32	12	12.5
11	--	--	--	31	22	20	32.2	16.7	17.2	--	17	15	30	12	11
12	34	23	20	33	22	20	38	18.0	19.0	--	17	16	25	9	10.5
13	34	20	18	33	22	21	--	--	--	--	17	13	27.5	9.6	9.0
14	--	21	19	33	23	22	33	19	18	--	14	13	30.0	13.0	10.0
15	36	23	20	--	--	--	--	14	16	--	14	10.5	--	--	--
16	37	22	20	--	21	20	31	17	16	--	12	10	27.5	10.5	10.0
17	31	19	20	--	--	--	--	--	--	--	--	--	--	--	--
18	--	--	--	25	24.5	25.0	--	17	16	--	14	14	--	12	9
19	--	22	21	--	21	20	30	16	15	--	14	14			
20	--	22	19	--	19	16	--	--	--	--	13.5	14.5			
21	36	21	19	35	18	17	31	18	17	--	14.0	13.5			
22	35	20	21	--	--	--	30	18	17	--	13.5	13.5			
23	36	22	21	--	19	19	--	17	17	--	14	13			
24	--	22	23	--	19	19	34	17	18	--	--	--			
25	--	--	--	--	20	20.5	35	18	18	--	12.5	12.0			
26	35	23	21	21	21	21	33	18	17	--	11.5	12.0			
27	35	23	22	20	20	20	--	--	--	22.5	11.5	9.5			
28	37	24	22	--	21	20	35	19	18	--	--	--			
29	32	23	22	--	--	--	33	16	16	--	10	7			
30	39	25	25	20	20	18	--	15	16	--	11	9			
31	33	25	24	--	--	--	32	15	15	--	--	--			
Ave	34.4	22.2	21	33.0	21.5	20.3	32.1	17.2	16.2	27.8	14.3	13.3	27.7	11.0	9.6

*In = Influent An = Anaerobic Al = Algae

APPENDIX B

Flow Data

B-1 July and August Flows

B-2 September and October Flows

B-3 November and December Flows

APPENDIX B-1

Daily Flows in Gallons Per Minute

Day	July				Aug			
	Inf*	Rec*	Trans*	Eff*	Inf	Rec	Trans	Eff
1					132	148	--	
2					132	148	--	
3					132	148	--	
4					--	--		
5					000	148	000	
6					000	148	000	
7					000	148	000	
8					000	148	000	
9					152	148	150	
10					152	148	150	
11					--	--	--	
12					152	148	150	
13					152	148	150	
14					152	148	150	
15					152	148	150	
16					152	148	150	
17					152	148	150	
18					--	--	--	
19					000	148	000	
20					000	148	000	
21					152	148	150	000
22					152	148	150	000
23	000	148	--	--	152	148	150	000
24	000	148	--	--	000	148	000	000
25	112	148	--	--	--	--	--	000
26	--	148	--	--	000	148	000	
27	--	148	--	--	152	148	150	000
28	--	148	--	--	152	148	150	152
29	000	148	--	--	152	148	150	152
30	125	148	--	--	152	148	150	152
31	132	148	--	--	152	148	150	152
Ave	61	148	--	--	105	148	100	22

* Inf = Influent Rec = Recirculant Trans = Pond 1 effluent
Eff = Effluent from algae pond (see Figure 5)

APPENDIX B-2

Daily Flows in Gallons Per Minute

Day	Sep				Oct			
	Inf*	Rec*	Trans*	Eff*	Inf	Rec	Trans	Eff
1	--	--	--	--	215	148	190	68
2	152	148	--	052	250	148	220	68
3	152	148	--	045	000	148	165	68
4	152	148	--	40	000	148	125	68
5	000	148	190	40	150	148	115	70
6	152	148	220	35	--	--	--	--
7	000	148	90	32	000	148	190	68
8	--	--	--	--	163	148	165	68
9	152	148	205	34	170	148	190	68
10	152	148	250	35	170	148	165	68
11	152	148	250	32	163	148	190	68
12	152	148	250	152	153	148	115	65
13	152	148	260	235	--	--	--	--
14	152	148	260	235	170	148	190	70
15	--	--	--	--	000	148	115	60
16	000	148	122	92	145	148	220	68
17	000	148	225	172	153	148	190	67
18	000	148	220	108	000	148	193	67
19	000	148	135	170	170	148	193	75
20	000	148	135	148	--	--	--	--
21	180	148	275	75	225	148	280	78
22	--	--	--	--	203	148	252	78
23	000	148	150	75	000	148	225	72
24	000	148	135	75	160	148	225	72
25	000	148	155	75	192	148	225	100
26	000	148	135	75	122	148	304	100
27	000	148	125	75	--	--	--	--
28	000	148	115	75	152	148	153	100
29	--	--	--	--	160	148	220	100
30	175	148	115	75	000	148	190	100
31	--	--	--	--	160	148	220	100
Ave	75	148	183	90	128	148	195	76

* Inf = Influent   Rec = Recirculant   Trans = Pond 1 effluent
Eff = Effluent from algae pond (see Figure 5)

APPENDIX B-3

Daily Flows in Gallons Per Minute

Day	Nov				Dec			
	Inf*	Rec*	Trans*	Eff*	Inf	Rec	Trans	Eff
1	122	148	220	100	--	--	--	--
2	100	148	220	100	000	000	000	00
3	--	--	--	--	000	075	000	00
4	000	148	005	100	000	105	048	00
5	000	000	000	90	000	092	000	00
6	000	000	000	90	098	090	168	00
7	067	000	049	83	132	092	170	00
8	040	000	049	83	--	--	--	--
9	067	000	033	183	098	092	138	68
10	--	--	--	--	068	092	138	68
11	000	000	000	000	115	092	198	68
12	000	000	000	000	135	092	131	68
13	000	000	000	000	122	092	151	68
14	000	000	000	000	170	128	220	68
15	000	000	000	000	--	--	--	--
16	000	000	000	000	210	105	220	98
17	--	--	--	--	000	000	000	00
18	000	000	000	000	--	--	--	--
19	000	000	000	000				
20	000	000	000	000				
21	000	000	000	000				
22	000	000	000	000	--	--	--	--
23	000	000	000	000				
24	--	--	--	--				
25	000	052	000	000				
26	000	075	48	000				
27	30	000	20	000				
28	--	--	--	--				
29	000	000	000	000				
30	000	000	000	000				
31	--	--	--	--				
Ave	17	23	26	33	82	82	113	36

* Inf = Influent Rec = Recirculant Trans = Pond 1 effluent
Eff = Effluent from algae pond (see Figure 5)

APPENDIX C

C-1 Unfiltered COD Values

C-2 Filtered COD Values

C-3 Unfiltered BOD Values

APPENDIX C-1

Unfiltered COD mg/1

Day	Aug			Sep			Oct			Nov			Dec		
	In*	An*	Al*	In	An	Al	In	An	Al	In	An	Al	In	An	Al
1										1428	595	578			
2	1860	274	232	2220	678	596	908	665	630				927	672	488
3															
4				1499	487	462	865	665	620	1307	802	677	2800	690	538
5	548	347	258												
6				321	607	610				1070	813	690	1680	608	522
7	--	240	213				1296	780	710						
8										1540	723	558			
9	1525	342	253	1095	647	498	2373	745	594				2240	655	399
10															
11				1439	619	512	1572	754	656	3643	764	674	2070	597	511
12	1195	355	271												
13				1530	640	536				1130	785	643	3060	788	538
14	2884	320	275				1710	825	540						
15										2220	705	672			
16	1258	484	315	1890	630	561	2770	762	735				3380	1022	757
17															
18				1340	553	503	1270	613	724	2060	642	551		1053	881
19	1440	364	238												
20				2670	705	553				2270	708	650			
21	1430	475	382				1130	818	685						
22										2458	610	575			
23	1590	466	365	2398	693	566	2920	860	630						
24															
25				1699	601	532	1110	732	605	2620	683	471			
26	1482	475	462												
27				1118	652	610				2183	788	678			
28	580	420	398				1066	876	766						
29										1590	674	517			
30	1696	491	427	1053	661	532	1410	693	620						
31															
	1450	389	314	1559	630	544	1570	750	656	1960	715	610	2308	759	579

*In = Influent An = Anaerobic Al = Algae

APPENDIX C-2

Filtered COD mg/1

Day	Aug			Sep			Oct			Nov			Dec		
	In *	An*	Al*	In	An	Al	In	An	Al	In	An	Al	In	An	Al
1										1245	139	114			
2	738	254	76	1018	271	135	730	133	124				1241	177	202
3															
4				1321	173	99	665	142	115	1210	228	196	2720	126	160
5	380	255	84												
6										1160	337	165	1700	141	141
7	--	151	93	--	132	140	687	115	89						
8										1500	295	197			
9	--	242	81	889	136	107	2125	98	98				1760	113	86
10															
11				859	132	144	1262	142	133	1873	218	140	1740	133	90
12	1090	204	195												
13				1240	178	153				1036	280	130	2640	179	109
14	1100	214	222				685	106	62						
15										1685	209	142			
16	825	320	89	1158	99	74	2700	186	18				1980	289	125
17															
18				618	65	53	1150	34	34	1340	234	125			
19	1282	212	102												
20				2350	114	143				1970	125	125			
21	828	195	153	--			980	196	77						
22										1380	125	67			
23	1473	288	102	--	--	--	1450	179	153						
24															
25				--	--	--	768	85	--	2180	128	118			
26	1138	212	119												
27				--	--	--				2100	272	262			
28	428	123	84				850	212	212						
29										1357	127	170			
30	1293	148	59	--	--	--	1285	155	138						
31															
Ave	961	217	112	1182	144	116	1180	137	104	1541	209	150	1969	165	130

*In = Influent An = Anaerobic Al = Algae

APPENDIX C-3

Unfiltered Biochemical Oxygen Demand 5-Day 20°C, Mg/l

Day	Aug			Sep			Oct			Nov			Dec		
	In*	An*	Al*	In	An	Al	In	An	Al	In	An	Al	In	An	Al
1										880	160	70			
2	917	145	75	1016	155	126	510	42	20				787	38	30
3															
4				1070	149	139	450	50	35	1205	197	107	1365	28	40
5	395	149	75												
6				288	190	186				1100	150	94	960	65	70
7	--	159	115				330	54	35						
8										980	141	65			
9	1070	165	85	832	237	143	980	97	63				864	53	43
10															
11				711	173	171	540	94	50	970	180	51	1120	113	53
12	743	183	95												
13				1270	232	177				885	165	60	1440	168	61
14	1060	197	62				645	76	68						
15										690	145	33			
16	1110	255	92	842	202	182	845	100	67				204	--	109
17															
18				990	204	173	510	103	49	574	126	26			
19	1105	220	98												
20				1710	237	120				1260	98	29			
21	818	202	116				516	70	66						
22										1200	74	33			
23	1238	215	103	1040	216	129	688	123	67						
24															
25				588	65	40	675	124	67	1043	49	52			
26	943	184	114												
27				478	75	58				945	42	56			
28	1282	142	114				360	101	65						
29										885	26	37			
30	1120	174	118	390	39	38	1072	145	76						
31															
Ave	985	184	98	863	167	130	625	91	56	971	119	55	963	78	58

*In = Influent An = Anaerobic Al = Algae

APPENDIX D

Physical Characteristics

D-1 pH

D-2 Dissolved Oxygen

D-3 Volatile Dissolved Solids

D-4 Dissolved Ash

D-5 Volatile Suspended Solids

D-6 Suspended Ash

D-7 Centrifuged Packed Solids Volumetric

D-8 Conductivity

D-9 Light Penetration

APPENDIX D-1

pH

Day	Aug			Sep			Oct			Nov			Dec		
	In*	An*	Al*	In	An	Al	In	An	Al	In	An	Al	In	An	Al
1	8.6	7.6	8.4				6.8	8.1	8.2	9.5	7.7	7.7			
2	8.7	7.5	8.2	8.4	8.0	8.4	7.4	8.4	8.2	8.3	7.5	7.6	6.0	6.8	6.8
3	8.7	7.7	8.1	6.9	8.0	8.4	7.3	8.2	8.3				7.6	6.8	6.8
4				9.6	7.9	8.5	7.0	8.2	8.3	7.7	7.8	7.4	11.0	6.0	6.4
5	7.4	7.6	8.0	9.0	8.0	8.3	7.1	8.2	8.2	6.3	7.1	7.7	7.6	6.0	6.9
6	9.9	7.7	8.0	6.9	8.1	8.2				6.5	7.4	7.5	6.0	7.0	7.2
7	--	7.6	7.6	7.4	8.0	8.5	7.4	8.2	8.9	8.4	7.6	7.8	7.6	6.4	6.8
8	--	7.6	7.9				9.2	8.5	8.3	9.1	7.7	7.7			
9	9.6	7.8	8.2	6.6	7.9	8.5	7.2	7.6	7.5	9.3	7.6	7.5	6.0	6.8	7.0
10	8.3	7.4	8.1	7.1	8.0	8.0	7.9	7.6	7.4				6.0	6.4	6.4
11				7.2	7.8	8.2	8.1	7.4	7.3	6.7	7.4	7.4	6.0	6.4	6.8
12	8.7	7.5	8.1	7.3	7.3	6.9	6.8	7.5	7.5	6.5	7.2	7.1	6.8	6.4	6.4
13	5.8	7.1	8.1	7.3	7.3	7.9				6.4	7.3	7.7	6.0	6.4	6.8
14	8.9	7.7	8.1	6.8	7.6	7.0	7.5	7.4	7.4	11.0	8.8	8.4	6.8	7.0	7.0
15	7.2	7.5	8.0				11.5	7.9	7.7	11.6	8.8	8.4			
16	7.4	7.4	8.2	7.1	7.9	7.9	11.2	8.3	7.6	6.9	7.1	7.2	6.4	6.4	6.8
17	8.4	7.5	7.9	7.7	7.9	7.9	7.3	7.7	7.7				11.0	6.4	6.4
18				6.9	7.4	7.8	6.8	7.7	7.8	8.0	7.2	7.0		6.4	6.4
19	6.9	7.6	8.1	6.9	8.1	8.1	6.6	7.6	7.4	9.0	8.0	8.0			
20	8.8	7.9	8.2	5.7	8.1	8.2				7.6	7.6	7.2			
21	8.3	7.8	7.9	6.2	8.0	8.1	7.0	7.7	7.4	9.2	7.4	7.8			
22	8.8	7.7	8.4				10.6	8.4	7.8	7.6	7.2	7.6			
23	11.4	7.4	8.5	6.6	7.9	8.2	11.2	8.5	7.8	7.1	7.0	7.8			
24	6.7	7.7	8.7	6.7	8.3	7.9	9.2	8.0	7.7						
25				6.8	8.1	8.1	8.2	7.8	7.7	11.0	7.2	7.0			
26	7.4	7.7	8.4	7.1	8.2	8.1	8.5	7.5	7.8	10.5	6.8	7.0			
27	7.1	7.8	8.1	7.2	8.3	8.1				6.4	6.8	7.0			
28	7.7	7.8	8.8	7.3	8.2	8.3	6.7	7.7	7.6						
29	9.3	7.9	8.1				8.1	7.9	7.7	6.6	8.0	8.1			
30	7.3	8.0	8.1	7.7	8.1	8.7	10.6	8.8	8.0	5.8	6.9	7.1			
31	6.9	7.7	8.7				8.7	7.8	7.8						
Min	5.8	7.1	7.6	5.7	7.3	6.9	6.6	7.4	7.3	5.8	6.8	7.0	6.0	6.0	6.4
Max	11.4	8.0	8.8	9.6	8.3	8.7	11.5	8.0	8.9	11.6	8.8	8.4	11.0	7.0	7.2

*In = Influent An = Anaerobic Al = Algae

APPENDIX D-2

PM Dissolved Oxygen in Algal Pond, Mg/l

Day	July	Aug	Sep	Oct	Nov	Dec
1		--	--	0.0	--	--
2		--	--	1.0	--	12.9
3		--	13.6	3.3		12.9
4		5.7	8.1	4.2	--	12.1
5		5.0	10.1	8.8	--	10.6
6		--	13.3	--	--	--
7		--	2.7	6.5	--	6.4
8		--	--	6.0	--	6.4
9		15.0	5.1	3.2	--	1.6
10		8.1	1.3	3.2		1.6
11		--	1.7	1.6	--	--
12		9.0	3.5	0.0	--	1.0
13		3.2	1.3	--	--	--
14		--	0.6	0.0	--	--
15		7.6	--	0.0	--	--
16		3.8	2.8	--	--	0.0
17		11.0	--	3.5		
18			--	0.0	--	
19		--	2.0	--	2.1	
20		0.2	2.5	--	3.2	
21		--	0.0	0.0	7.9	
22		6.9	--	0.0	6.5	
23		--	0.0	0.0	5.2	
24	11.8	0.6	0.0	0.0		
25	10.3		--	--	10.5	
26	--	0.0	0.0	--	10.3	
27	--	0.0	0.0	0.0	14.0	
28	--	--	--	0.0		
29	15.7	1.1	--	--	11.7	
30		1.8	0.1	--	12.5	
31	10.6	0.0		--		
Ave	12.1	3.5	3.1	2.0	8.39	4.6

APPENDIX D-3

Volatile Dissolved Solids, Mg/l

Day	Jul			Aug			Sep			Oct			Nov			Dec		
	In**	An **	Al **	In	An	Al	In	An	Al	In	An	Al	In	An	Al	In	An	Al
1				1186	340	306	--	--	--	--	--	--	1896	924	800	--	--	--
2				1214	402	278	1304	460	236	1050	472	492	478	516	1278	1698	942	882
3				1890	468	376	1306	510	340	864	180	350	--	--	--	3472	528	202
4				--	--	--	456	458	582	718	846	490	1608	596	442	806	240	444
5				550	502	340	1146	492	374	710	376	444	1410	450	366	1654	580	550
6				2240	196	138	352	438	302	--	--	--	1254	600	452	1626	300	322
7				--	402	330	1244	548	104	848	414	294	1326	533	450	1920	616	486
8				236	236	214	--	--	--	1366	572	448	598	492	408	--	--	--
9				1752	504	368	1012	494	464	2018	976	944	2562	596	678	1912	520	418
10				1886	578	538	1020	392	388	1134	550	414	--	--	--	1836	424	400
11				--	334	250	1030	550	280	1580	860	1190	2538	3328*	770	--	524	412
12				876	608	300	1432	428	480	998	442	406	1252	648	398	2138	678	572
13				3900*	--	--	1360	372	358	--	--	--	1218	564	364	2052	662	568
14				1378	536	330	488	502	1208	1204	442	312	3228*	318	390	2724	526	--
15				1134	--	--	--	--	--	1526	954	1042	1592	624	374	2622	--	--
16				1078	418	298	832	288	574	1272	310	308	1656	932	784	--	2270*	1180*
17				1198	360	344	1342	618	350	1042	726	564	--	--	--	3452	1330	1016
18				--	--	--	1124	576	512	986	468	454	1550	380	312	4964*		
19				1908	1062	898	1556	486	424	812	558	464	2094	--	--			
20				1140	648	394	2000	470	490	--	--	--	1214	918	650			
21				848	256	216	1732	492	470	822	416	412	2040	666	404			
22				1788	630	508	--	--	--	1880	730	506	1462	484	344			
23				1580	488	314	--	--	--	1590	820	694	1306	538	394			
24				1682	798	708	--	--	--	1552	744	594	--	--	--			
25				--	--	--	--	--	--	1376	604	500	522	364	358			
26				1120	310	292	--	--	--	1500	638	448	1794	364	426			
27				1666	1152	1070	--	--	--	--	--	--	1846	276	390			
28				1472	440	260	--	--	--	972	768	634	--	--	--			
29				1614	330	246	--	--	--	1348	684	522	1394	410	376			
30	1070	294	264	1416	760	430	--	--	--	1526	500	388	1684	604	562			
31	880	372	272	1102	752	422	--	--	--	1802	752	406						
Ave	975	333	268	1358	520	391	1150	477	441	1250	608	528	1513	557	507	2142	606	52

*Excluded from Ave.
**In = Influent An = Anaerobic Al = Algae

APPENDIX D-4

Dissolved Ash, Mg/l

Day	Aug			Sep			Oct			Nov			Dec		
	In**	An**	Al**	In	An	Al	In	An	Al	In	An	Al	In	An	Al
1	1046	984	1158	--	--	--	--	--	--	976	494	584	--	--	--
2	1108	1136	1186	1288	1010	1028	1106	966	1046	790	822	1030	968	482	536
3	1346	1108	1172	466	972	1024	1146	1262	1436	--	--	--	1162	986	1092
4	--	--	--	352	1028	854	778	920	1048	1106	842	992	1528	1190	1234
5	886	1040	1144	1038	968	1010	994	1110	984	1360	1170	1066	1094	878	846
6	1338	1278	1324	1004	1042	920	--	--	--	1352	958	1036	1046	1150	1780
7	--	1168	1220	998	912	426	1020	1046	510	1164	1020	1020	1038	996	1120
8	--	1142	1136	--	--	--	726	776	958	1146	982	1054			
9	--	1102	1198	1064	964	1010	700	426	520	536	936	858	1072	1008	1036
10	964	1004	1050	1154	1514	1436	948	626	1058	--	--	--	1136	728	1140
11				1046	360	164	620	568	444	892	578	716	1138	998	1044
12	1120	1226	1234	1234	1016	1042	1508	988	962	1314	972	1060	1012	926	934
13	2980	572	1244	1254	500	1050	--	--	--	1332	1014	1090	1000	1152	1070
14	1008	1096	1212	942	546	1092	1066	956	1256	4302*	1106	1086	1030	964	634
15	1068	--	1148	--	--	--	1020	416	632	1488	974	1028	--	--	--
16	1114	1134	1264	1222	870	1084	1132	1028	1140	794	286	600	1592	394	456
17	1064	1010	1124	1078	940	1254	764	700	956	--	--	--	996	492	440
18	--	--	--	1128	1058	1086	1006	934	1012	1176	790	1042	--	--	--
19	452	484	650	1286	988	1030	1044	858	1044	1316	--	920			
20	1072	1078	1338	1778	934	1004	--	--	--	1006	626	780			
21	1008	1210	1222	1724	902	1084	1072	1010	1130	1260	848	1006			
22	1020	980	1032	--	--	--	876	826	902	1236	930	1018			
23	1434	1158	1282	--	--	--	874	552	726	1314	912	1018			
24	1212	788	618	--	--	--	696	778	804	--	--	--			
25	--	--	--	--	--	--	920	756	984	2300	1130	1112			
26	1168	1176	1084	--	--	--	998	810	950	1564	1070	1044			
27	594	372	418	--	--	--	--	--	--	1416	1274	1234			
28	1092	1034	1178	--	--	--	814	724	748	--	--	--			
29	1240	1156	1082	--	--	--	828	698	870	1272	1024	1072			
30	1010	678	934	--	--	--	1226	924	1022	1072	820	842			
31	766	938	1030	--	--	--	1016	824	1046						
Ave	1128	1002	1099	1118	922	978	946	831	930	1215	898	935	1129	884	954

*Excluded from Ave.

**In = Influent An = Anaerobic Al = Algae

APPENDIX D-5

Suspended Volatile, Mg/l

Day	Jul			Aug			Sep			Oct			Nov			Dec		
	In **	An **	Al **	In	An	Al	In	An	Al	In	An	Al	In	An	Al	In	An	Al
1				930	103	121	--	--	--				119	437	449	--	--	--
2				672	92	115	148	356	303	223	350	345	411	436	146	68	415	285
3				80	97	118	416	145	341	146	411	379	160	454	418	149	440	359
4				--	--	--	185	368	344	122	375	367	--	--	--	56	409	314
5				49	90	120	3265*	379	478	69	362	427	71	374	423	95	252	282
6				1385	60	105	94	343	478	--	--	--	592	383	449	439	94	307
7				--	60	86	451	358	311	117	286	383	94	375	427	208	440	328
8				--	71	38	--	--	--	265	358	378	113	392	409	--	--	--
9				119	69	129	262	407	307	239	446	407	26	383	416	406	492	379
10				148	61	143	256	429	491	187	426	393	128	507	51	428	586	403
11				--	--	--	191	383	300	242	444	394	--	--	--	850	539	404
12				83	76	96	354	396	438	227	406	334	145	395	438	448	471	481
13				82	91	139	541	472	321	--	--	--	141	372	437	318	510	429
14				66	94	132	121	404	350	138	457	414	125	411	380	327	605	480
15				243	--	193	--	--	--	98	436	448	81	433	454	--	--	--
16				179	133	183	118	359	351	243	481	409	3	418	331	576	757	519
17				43	86	115	250	396	384	337	491	399	226	415	399	259	867	573
18				--	--	--	376	414	517	417	552	506	--	--	--			
19				130	103	127	325	360	354	211	385	417	251	458	464			
20				207	143	157	189	433	371	--	--	--	160	439	424			
21				120	101	108	271	396	301	133	521	415	238	426	385			
22				265	164	189	--	--	--	231	489	503	994	409	398			
23				94	167	144	--	--	--	424	534	474	37	406	373			
24				177	153	228	--	--	--	268	560	523	94	428	317			
25				--	--	--				223	559	542	--	--	--			
26				104	179	224				78	474	394	506	427	319			
27				174	198	251				--	--	--	173	320	364			
28				204	223	232				178	559	340	--	--	--			
29				70	226	241	--	--	--	163	460	447	75	434	297			
30	105	88	103	144	192	264				242	469	294	18	385	243			
31	2470*	79	84	247	296	228				240	469	407	--	--	--			
Ave	105	84	94	241	128	156	378	376	374	199	452	414	199	413	369	327	492	395

*Excluded from Ave.

**In = Influent An = Anaerobic Al = Algae

APPENDIX D-6

Suspended Ash, Mg/1

Day	Jul			Aug			Sep			Oct			Nov			Dec		
	In**	An**	Al**	In	An	Al	In	An	Al	In	An	Al	In	An	Al	In	An	Al
1				--	22	17							149	0	27	--	--	--
2				846	9	8	136	60	57	465	113	105	189	83	109	68	17	51
3				79	24	23	244	5	94	142	102	76	203	52	36	116	22	32
4				--	3	8	260	58	81	263	120	129	--	--	--	0	34	59
5				--	28	33	1264	82	149	66	87	145	0	34	41	110	30	66
6				--	1	--	86	76	144	--	--	--	301	16	51	754	17	26
7				--	--	--	540	48	39	225	61	156	137	25	34	576	87	76
8				--	13	16	--	--	--	539	116	110	211	49	49	--	--	--
9				218	11	21	370	86	46	474	106	94	299	98	63	758	125	9
10				304	35	35	946	139	124	441	91	86	132	481	66	769	179	77
11				--	--	--	292	80	58	465	150	122	--	--	--	169	104	84
12				148	0	2	595	83	103	622	108	105	39	21	75	880	256	149
13				3	22	30	1098	168	74	--	--	--	5	40	72	809	157	102
14				--	--	--	86	51	57	241	81	77	84	55	95	699	196	230
15				190	24	22	--	--	--	249	148	125	81	91	97	--	--	--
16				398	32	17	87	140	48	724	243	161	62	158	152	619	536	194
17				68	28	28	423	82	93	1044	178	83	464	46	79	291	364	208
18				56	0	15	689	89	158	949	260	132	--	--	--			
19				318	30	30	669	89	102	502	191	141	482	46	41			
20				269	48	29	129	86	85	--	--	--	237	36	76			
21				--	--	--	466	46	62	29	211	159	272	68	192			
22				586	41	21	--	--	--	451	211	128	--	53	91			
23				157	41	0				1051	255	163	42	78	73			
24				159	75	39				593	265	201	200	50	67			
25				--	--	--				458	248	241	--	--	--			
26				174	40	68				228	148	121	1237	51	69			
27				90	23	22				--	--	--	181	199	66			
28				323	40	36				283	100	252	--	--	--			
29				120	16	55	--	--	--	233	161	108	24	67	59			
30	148	5	12	184	39	31				440	175	48	73	78	100			
31	6030*	33	29	318	6	67				425	106	125	--	--	--			
Mean	--	19	20	239	25	27	465	82	88	447	155	131	212	79	75	472	152	98

*Excluded from Mean

**In = Influent An = Anaerobic Al = Algae

APPENDIX D-7

Solids Packed Wet Volume of Solids Mg Per Liter

Day	Aug			Sep			Oct			Nov			Dec		
	In**	An**	Al**	In	An	Al	In	An	Al	In	An	Al	In	An	Al
1	5.0	0.6	0.7				2.8	2.5	2.3	0.7	1.5	1.4			
2	2.7	0.75	1.2	0.8	2.0	2.5	1.8	2.0	1.7	1.0	1.0	1.2	0.3	1.0	0.2
3	0.3	0.70	0.8	2.2	1.5	2.3	1.2	2.0	3.0	1.3	1.0	1.0	0.5	1.0	2.5
4	0.5	1.4	1.8	1.2	1.8	1.7	1.5	2.5	2.8				0.3	0.5	0.4
5				3.7	1.3	3.5	0.4	1.5	2.5	0.2	0.7	1.0	0.5	0.4	1.5
6	17.5*	0.5	0.7	0.4	1.8	3.6				0.3	0.7	1.0	2.9	0.5	2.0
7	--	0.5	0.5	2.0	1.5	2.5	1.0	1.5	1.5	1.0	0.4	0.6	1.5	1.6	1.8
8	--	0.7	1.2				1.8	0.8	2.8	1.2	0.8	0.9			
9	0.9	0.4	1.0	1.5	1.5	3.8	1.9	0.8	2.0	1.0	0.9	1.5	3.2	0.5	0.4
10	1.2	0.5	1.8	1.0	1.5	4.5	1.7	1.5	4.5				3.1	0.5	0.2
11	1.5	1.0	2.0	1.2	2.0	2.5	1.8	1.2	2.5	1.0	0.5	1.0	3.0	0.8	2.0
12				2.8	1.5	4.5	2.0	1.5	2.7	0.5	1.0	1.0	3.0	5.0	2.0
13	0.2	0.5	1.2	3.5	1.5	4.0				0.3	0.5	0.6	2.5	1.0	1.5
14	0.7	1.0	1.3	0.9	1.0	2.7	1.5	1.5	2.5	0.3	1.0	0.5	2.7	2.5	2.0
15	2.0	0.5	2.5				1.0	2.0	2.5	0.3	0.7	0.5			
16	1.2	1.2	1.2	0.4	1.0	2.5	2.4	4.0	3.2	0.5	1.5	1.0	5.5	4.0	0.4
17	1.2	1.7	1.3	0.7	1.4	2.5	3.5	1.5	1.2				1.2	4.0	0.5
18				2.5	2.0	4.0	3.6	1.0	2.5	2.0	1.0	1.4	--	4.0	0.6
19	1.1	0.7	1.1	3.0	1.0	1.2	2.5	1.0	2.5	1.0	1.5	1.5			
20	1.0	2.0	1.0	1.0	1.5	2.3				0.6	1.4	2.0			
21	1.5	1.5	0.8	2.1	0.9	3.5	1.0	1.5	2.5	0.6	1.0	2.0			
22	1.8	1.5	1.5				2.0	1.2	2.5	0.7	0.5	1.5			
23	0.8	1.7	1.3	6.4	3.5	3.0	3.6	2.5	2.5	0.2	1.0	2.5			
24	0.9	1.8	1.5	0.8	2.5	2.0	1.8	2.0	6.5						
25				1.0	1.5	2.0	1.5	5.0	4.5	0.8	0.9	0.3			
26	0.4	1.0	2.8	0.8	1.0	2.0	0.8	0.6	0.9	6.8	1.0	3.0			
27	1.0	1.0	1.8	0.8	1.0	1.8				0.5	0.8	2.5			
28	1.1	0.7	1.5	0.5	0.5	1.2	2.5	2.0	1.5						
29	0.7	1.8	2.0				1.5	1.5	1.0	0.4	1.0	5.0			
30	0.8	0.8	2.0	4.1	2.5	1.5	1.8	5.0	5.0	0.5	0.7	2.5			
31	1.2	1.0	1.5				1.5	1.0	1.0						
Mean	1.2	1.0	1.4	1.8	1.6	2.7	1.9	1.9	2.6	0.9	0.9	1.5	2.2	1.8	1.2

*Excluded from Mean

**In= Influent An = Anaerobic Al = Algae

APPENDIX D-8

Specific Conductance Micromhos

Day	Aug			Sep			Oct			Nov			Dec		
	In*	An*	Al*	In	An	Al	In	An	Al	In	An	Al	In	An	Al
1	290	210	390				280	280	270	340	370	370	--	--	--
2	310	290	300	310	300	300	325	320	310	320	330	335	320	370	390
3	290	280	260	280	280	296	350	310	290				283	360	405
4				405	310	340	370	330	290	350	370	350	170	435	385
5	310	270	250	420	330	325	270	260	280	320	310	331	270	390	400
6	245	290	280	325	290	290	--	--	--	295	310	380	400	460	290
7	--	280	270	340	295	320	350	330	350	342	310	345	405	350	370
8	--	270	280	--	--	--	390	330	340	365	335	349	--	--	--
9	250	280	270	320	300	300	320	340	340	372	340	360	370	340	380
10	352	250	253	330	312	296	340	330	340				380	360	360
11				305	295	290	340	320	310	350	340	335	410	390	385
12	320	270	270	240	290	265	290	270	315	345	337	327	445	415	400
13	301	295	289	300	320	295				320	325	370	423	400	405
14	400	310	290	300	310	290	310	340	320	90	323	405	420	390	395
15	350	290	270	--	--	--	220	350	350	123	360	400			
16	370	310	300	320	330	290	298	343	335	245	350	320	278	380	380
17	400	300	310	310	300	280	415	395	332	--	--	--	275	390	450
18	--	--	--	270	273	249	310	316	290	280	341	360			
19	380	360	285	250	290	270	332	330	310	219	330	355			
20	410	300	290	172	275	260	--	--	--	235	320	345			
21	430	330	300	180	280	250	325	311	282	218	312	348			
22	389	335	320	--	--	--	335	335	329	275	330	351			
23	290	302	298	280	310	280	244	332	299	230	300	310			
24	305	282	295	300	285	270	350	368	320	--	--	--			
25	--	--	--	285	300	290	321	310	303	200	320	355			
26	280	280	300	270	285	270	342	361	340	230	390	400			
27	330	285	280	310	300	275				410	380	294			
28	370	290	300	240	260	290	272	390	355	--	--	--			
29	272	289	299				370	360	350	320	360	335			
30	275	284	293	285	275	285	350	375	360	290	310	305			
31	373	273	285				350	370	355						
Ave	332	289	289	293	294	287	329	334	321	283	337	349	346	387	384

*In = Influent An = Anaerobic Al = Algae

APPENDIX D-9

Light Penetration, cm

Day	Aug			Sep			Oct			Nov			Dec		
	In**	An**	Al**	In	An	Al	In	An	Al	In	An	Al	In	An	Al
1	64	88	78	--	--	--	22	20	30	88	30	30	--	--	--
2	24	72	64	70	36	40	32	30	36	78	28	32	64	32	40
3	26	66	64	36	20	32	28	20	20	--	--	--	76	42	40
4				60	36	44	40	22	18	40	20	14	200*	36	30
5	138	100	62	24	22	22	88	34	34	114	36	18	72	38	38
6	40	88	65	62	30	36	78	26	24	68	36	32	30	32	34
7	--	86	84	42	36	44	--	--	--	48	36	34	22	30	38
8	--	80	88	--	--	--	30	24	22	58	28	26	--	--	--
9	64	84	64	44	24	52	32	24	28	60	32	28	30	28	30
10	42	78	72	46	36	42	28	24	28	--	--	--	30	30	34
11	--	--	--	50	24	46	34	24	24	48	30	34	26	24	34
12	40	62	62	34	34	48	44	42	56	61	28	32	38	32	34
13	--	80	80	26	32	40	32	22	24	46	34	36	32	26	30
14	62	64	72	44	28	36	--	--	--	38	36	32	28	26	32
15	42	54	50	--	--	--	30	140*	26	30	30	34	--	--	--
16	48	58	46	58	28	42	36	34	38	62	44	36	10	16	20
17	62	50	56	44	38	52	30	32	42	--	--	--	16	24	24
18	--	--	--	44	28	34	20	24	42	26	30	32	--	20	24
19	60	52	58	24	24	44	46	28	28	36	30	30			
20	52	62	60	42	28	30	54	32	34	46	36	40			
21	42	52	62	34	30	36	--	--	--	42	38	36			
22	66	62	56	--	--	--	36	34	42	28	26	30			
23	76	50	62	6	4	44	30	28	32	70	30	36			
24	60	58	52	48	30	26	34	32	36	--	--	--			
25	--	--	--	50	26	40	36	28	28	38	30	32			
26	52	44	48	46	26	30	34	24	34	32	38	40			
27	52	50	50	50	30	32	44	20	20	56	38	38			
28	50	60	50	80	40	26	--	--	--	--	--	--			
29	52	44	46	--	--	--	40	20	34	56	30	50			
30	38	40	42	22	32	42	60	20	18	50	30	48			
31	48	56	52	--	--	--	46	14	18	--	--	--			
Ave	55	77	61	43	28	38	39	26	30	53	32	33	36	29	32

*Excluded from Ave.
**In = Influent An = Anaerobic Al = Algae

APPENDIX E

Chemical Characteristics

E-1 Magnesium

E-2 Calcium

E-3 Sulfate

E-4 Sulfide

E-5 Organoleptic Odor

APPENDIX E-1

Magnesium Mg Per Liter

Day	Aug			Sep			Oct			Nov			Dec		
	In *	An *	Al *	In	An	Al	In	An	Al	In	An	Al	In	An	Al
1	18	9.1	8				--	--	--						
2							--	--	--	72	30	11			
3	--	--	--	52	48	29	--	--	--				32	41	49
4															
5	46	54	65	69	29	31				48	47	55	40	46	31
6	73	54	60												
7				41	53	51				55	42	47	21	57	50
8	--	49	57				--	--	--						
9										18	33	14			
10	75	24	82	35	48	30	--	--	--				83	70	49
11															
12				25	26	37	--	--	--	41	28	29	44	58	53
13	141	48	60												
14				75	29	25				28	17	26	18	57	51
15	51	23	43				--	--	--						
16										65	74	47			
17	48	51	60	69	44	32	--	--	--				--	80	48
18															
19				25	48	61	--	--	--	86	90	44			
20	42	53	61												
21				52	40	66				43	72	41			
22	35	34	42				--	--	--						
23										38	97	50			
24	41	70	50	56	42	40	28	52	44						
25															
26				39	52	50	87	85	78	121	93	58			
27	39	56	56							46	28	46			
28				32	46	55									
29	39	56	57				133	76	73						
30				--	--	--				58	45	45			
31	65	38	51				51	84	80						
	55	44	54	48	42	42	75	75	69	55	54	40	40	58	47

*In = Influent   An = Anaerobic   Al = Algae

APPENDIX E-2

Calcium Mg Per Liter

Day	Aug			Sep			Oct			Nov			Dec		
	In*	An*	Al*	In	An	Al	In	An	Al	In	An	Al	In	An	Al
1	210	174	179				216	84	82						
2										80	92	114			
3	224	104	80	196	111	76	176	80	90				100	116	108
4															
5	209	118	106	160	115	89	192	78	89	216	150	128	220	122	124
6	280	134	124												
7				134	85	64				172	130	126	148	103	104
8	--	118	102				140	74	72						
9										304	118	140			
10	196	190	124	194	64	84	180	98	90				184	70	104
11															
12				260	96	100	142	76	20	220	130	116	164	108	122
13	340	126	114												
14				172	98	112				1152*	155	146	214	116	128
15	148	164	148				336	72	60						
16										276	58	118			
17	148	108	118	226	82	136	136	98	86				142	94	166
18															
19				202	78	86	156	94	102	92	54	118	--	158	156
20	92	119	103												
21				242	82	114				124	50	118			
22	136	155	148				188	46	44						
23										296	128	118			
24	392	134	104	186	85	100	128	93	97						
25															
26				256	78	80	46	40	43	76	40	106			
27	192	112	78							226	128	115			
28				288	84	40									
29	96	108	46				60	52	48						
30				--	--	--				216	98	110			
31	304	132	66				96	54	46						
Ave	212	133	103	201	81.0	90.0	157	74	69	191	102	124	168	111	127

*In = Influent An = Anaerobic Al = Algae

APPENDIX E-3

Sulfate Concentrations Mg Per Liter

Day	Aug			Sep			Oct			Nov			Dec		
	In **	An **	Al **	In	An	Al	In	An	Al	In	An	Al	In	An	Al
1	128	95	256				16	25	23						
2										206	15	40			
3	146	95	270	294	49	87	208	59	82				49	35	17
4															
5				240	43	109	171	53	112	186	57	66	194	71	100
6	256	110	173												
7				623	105	49				242	23	31	232	74	87
8	--	135	71				231	82	102						
9										112	89	87			
10	1500*	81	234	285	81	46	254	48	128				230	110	127
11															
12				250	40	25	1400*	146	87	231	198	165	97	79	92
13	153	64	69												
14				278	--	12				290	35	120	253	--	100
15	212	54	107				140	18	71						
16										232	84	130			
17	220	25	84	242	92	33	244	15	78				46	45	65
18															
19				216	56	97	247	76	95	230	49	69			
20	224	8	61												
21				253	34	64				311	71	123			
22	296	115	127				240	92	117						
23										69	52	138			
24	290	114	124	231	58	63	100	97	265						
25															
26				138	15	77	149	96	79	240	48	107			
27	257	51	46							123	58	124			
28				158	77	113									
29	326	283	90				174	43	53						
30										191	106	94			
31	309	67	100				229	23	69						
Mean	235	93	130	267	59	65	185	62	97	205	68	100	158	69	84

*Excluded from Mean
**In = Influent An = Anaerobic Al = Algae

APPENDIX E-4

Dissolved Sulfides Mg Per Liter

Day	Aug			Sep			Oct			Nov			Dec		
	In *	An *	Al *	In	An	Al	In	An	Al	In	An	Al	In	An	Al
1	0	6.0	0				0.2	0.2	0	--	--	--			
2	0	5.0	0	0	0.8	0	0.2	0.2	0	--	--	--	9.6	0	0
3	0	4.0	0	0	0.6	0	0.3	0.2	0				0.1	0	0
4				0	0	0	0.4	0.2	0	--	--	--	0.1	3.0	0
5	0.2	5.6	0	0	0.2	0	0.7	0	0	0.1	0.8	0.0	0.1	2.0	0
6	0	0.4	0	0	0	0				0.1	0.7	0.2	0.1	0.2	0
7	--	4.0	0.4	0	0	0	0.4	0.2	0	0.2	0.3	0.3	0.1	0.2	0
8	--	0.4	0				0.2	0.2	0.1	0.2	0.6	0.0			
9	0	2.4	0	0	0.2	0	0	0.2	0	0.3	0.7	0.0	0.1	0.2	0
10	0	6.2	0.3	0	0.2	0	0.2	0.2	0				0.2	0.2	0
11				0	0.1	0	0	0.2	0	0	1.3	0	0.3	0.0	0.1
12	0	4.4	0.0	0	0	0	0	0.3	0	0	1.6	0	0.2	0.3	0
13	0	0.1	0	0.3	0.2	0				0	0.3	0	0.1	0.5	0.3
14	0	0	0	0	0.3	0	0	0.2	0	0	0.3	0	0.0	1.2	0
15	0	0.7	0				0.2	0.2	0	--	--	--			
16	0	0.2	0	0.7	0.2	0	0.1	0.25	0	0	0.3	0	0.3	6.5	0.2
17	0	0.1	0	0.2	0.15	0	0	0.3	0						
18				0.8	0.12	0	0	0.3	0	--	--	--			
19	0.8	1.1	0	0.1	0.25	0	.05	0.3	0	--	--	--			
20	0	2.5	0	0	0.20	0				--	--	--			
21	0	0.4	0.9	0.4	0.35	0	0	0.2	0	--	--	--			
22	0	1.4	0				0	0.2	0	--	--	--			
23	0	2.4	0	0.2	0.4	0	0	0.5	0	--	--	--			
24	0	1.7	0	0.25	0.4	0	0	0.6	0						
25				0.1	0.3	0	0	0.8	0	--	--	--			
26	0	1.2	0	3.5	1.5	0	0	0.8	0.1	--	--	--			
27	0	0.5	0	0.0	0.3	0				0.1	0.3	0.0			
28	0	0.5	0	0.2	0.15	0	--	--	--						
29	0	1.5	0				0.1	0.7	0	0.2	0.5	0.0			
30	0	0.3	0	0.2	0.2	0.0	--	--	--	2.5	0.0	0.0			
31	0	6.5	0				0	0.4	0						
Ave	0.04	2.2	.06	0.3	0.28	0.0	0.13	0.32	.01	0.3	.59	.04	0.87	1.1	.05

*In = Influent An = Anaerobic Al = Algae

APPENDIX E-5

Organoleptic Odor Levels

Day	Aug			Sep			Oct			Nov			Dec		
	In *	An*	Al *	In	An	Al	In	An	Al	In	An	Al	In	An	Al
1	8	20	4				10	6	1	12	20	15			
2	6	20	10	15	12	3	8	10	9	12	20	15	12	8	3
3	6	15	15	8	12	3	20	25	9				24	1	1
4				6	16	3	25	12	9	18	15	12	4	6	1
5	8	8	4	4	12	3	24	8	1	24	4	8	4	4	1
6	8	6	4	6	12	1				20	18	6	6	1	1
7	--	8	6	6	12	1	20	6	6	15	30	8	6	1	1
8	--	15	10				8	16	6	20	24	12			
9	8	6	4	6	12	1	16	6	3	20	24	12	15	4	3
10	6	12	6	8	12	1	16	6	6				4	10	1
11				6	12	1	16	1	1	18	8	8	8	15	1
12	8	12	10	18	12	1	12	4	1	8	18	20	4	15	1
13	4	24	6	8	16	1				18	8	1	4	15	1
14	8	12	1	6	18	3	16	6	6	2	16	1	4	15	1
15	6	12	6				16	8	1	16	8	8			
16	6	18	1	8	16	1	8	4	1	15	4	3	12	18	8
17	6	16	6	8	12	1	8	4	6				8	16	6
18				8	8	3	8	15	1	4	16	1	9	16	12
19	16	18	1	6	12	1	8	6	1	10	10	1			
20	16	18	1	8	16	6				--	--	--			
21	10	12	15	12	12	1	6	10	1	8	16	3			
22	4	16	3				10	10	1	8	10	1			
23	18	16	6	8	6	18	20	8	1	8	12	1			
24	10	24	3	8	6	1	20	15	6						
25				10	6	1	6	10	6	18	8	3			
26	8	20	6	10	6	1	24	3	3	10	8	1			
27	6	12	3	30	8	1				6	8	1			
28	6	12	3	8	15	3	12	12	3						
29	8	16	1				12	18	10	12	8	1			
30	12	12	16	6	4	6	8	25	12	15	15	3			
31	6	12	3				24	25	1						
Ave	7.3	14.5	5.7	9.3	11.4	2.6	13.6	10.3	4.1	13.1	13.1	6.0	8.0	9.8	2.8

* In = Influent An = Anaerobic Al = Algae

APPENDIX F

Nutrients - Nitrogen and Phosphorus

F-1 Tabulation of Nitrate-N Values
F-2 Tabulation of Ammonia-N Values
F-3 Tabulation of Total N Values
F-4 Tabulation of Phosphate Data

APPENDIX F-1

Nitrate Nitrogen Mg Per Liter

Day	Aug			Sep			Oct			Nov			Dec		
	In*	An*	Al*	In	An	Al	In	An	Al	In	An	Al	In	An	Al
1	4.9	0.4	0.5				2.3	0.8	1.2						
2										3.8	0.3	0.2			
3	5.6	0.6	0.9	1.8	0.4	0.4	4.3	0.9	0.9				0.8	0.2	0.7
4															
5				2.8	0.3	0.4	0.5	0.4	0.4	0.5	0.1	0.1	5.4	0.5	1.0
6	4.5	0.4	0.3												
7				1.9	0.4	0.3				5.0	0.3	0.3	3.8	0.4	0.9
8		0.3	0.3				3.8	0.2	0.2						
9										5.7	0.3	0.7			
10	0.1	0.5	0.8	3.2	0.4	0.3	1.2	0.5	0.4				1.9	0.5	0.4
11															
12				1.0	0.5	0.4	0.1	0.4	0.3	0.7	0.4	0.4	3.4	0.5	0.7
13	1.5	0.3	0.4												
14				0.6	0.4	0.3				6.8	0.3	0.2	1.7	0.3	0.8
15	1.8	0.4	0.3				3.1	0.5	0.1						
16										5.8	0.5	0.5			
17	3.0	0.3	0.2	1.0	0.3	0.3	1.6	0.4	0.3				5.0	0.4	0.3
18															
19				1.4	0.3	0.7	0.4	0.5	0.7	5.1	0.3	0.4		0.8	0.6
20	2.2	0.3	0.4												
21				1.6	0.4	0.3				7.1	0.4	0.5			
22	3.2	0.2	0.5				7.8	0.4	0.6						
23										0.5	0.5	0.7			
24	1.2	0.4	0.2	1.6	0.7	0.6	3.6	0.4	0.5						
25															
26				0.2	0.4	0.3	4.3	0.4	0.4	9.8	0.9	0.8			
27	1.3	0.4	0.3							4.8	1.3	1.3			
28				0.3	0.6	0.5									
29	7.6	0.2	0.3				3.8	0.6	0.5						
30										0.5	0.6	1.0			
31	1.7	0.3	0.5				8.0	0.7	0.5						
Ave	2.97	0.36	0.42	1.45	0.42	0.40	3.2	0.51	0.50	4.31	0.48	0.55	3.14	0.45	0.67

*In = Influent An = Anaerobic Al = Algae

APPENDIX F-2

Ammonia Nitrogen Mg Per Liter

Day	Aug			Sep			Oct			Nov			Dec		
	In *	An *	Al *	In	An	Al	In	An	Al	In	An	Al	In	An	Al
1	1.9	0.5	0.3				0.5	2.5	0.9						
2										2.1	2.9	3.3			
3	1.6	0.7	0.1	1.1	0.9	0.3	1.6	1.1	0.4				2.2	1.5	1.7
4															
5				1.1	0.7	0.4	1.8	0.0	0.0	1.2	1.4	0.9	1.8	1.4	1.9
6	1.5	1.4	0.5												
7				1.2	0.5	0.0				2.5	1.1	0.9	1.4	1.4	1.2
8	--	1.9	1.2				1.5	0.7	0.3						
9										1.7	1.7	0.7			
10	1.4	0.9	0.2	1.3	0.6	0.2	1.4	1.0	0.9				1.6	1.1	1.3
11															
12				1.5	0.7	0.6	1.4	0.0	0.0	3.5	2.1	0.9	1.4	1.8	1.1
13	2.1	2.3	2.1												
14				1.8	1.3	0.5				1.0	1.5	1.6	1.2	0.7	0.4
15	1.3	1.0	0.3				1.8	0.4	0.9						
16										5.4	1.1	1.2			
17	2.4	1.6	1.2	1.7	0.5	0.2	1.1	0.6	0.3				1.2	1.6	0.5
18															
19				1.4	0.5	0.5	0.7	0.2	0.2	1.5	1.7	1.2	--	0.9	0.7
20	1.3	1.1	0.7												
21				0.9	0.3	0.0				1.8	1.6	0.5			
22	1.0	1.2	0.7				1.4	0.9	0.7						
23										5.3	1.1	0.6			
24	1.4	0.6	0.0	0.2	0.1	0.0	1.8	0.5	0.4						
25															
26				1.4	0.5	0.7	2.3	1.4	1.1	1.6	1.8	1.8			
27	1.2	0.5	0.5							4.8	1.3	1.3			
28				1.6	0.4	0.2									
29	1.1	1.1	0.3				0.9	0.7	0.9						
30										3.5	1.9	2.1			
31	3.1	1.8	1.5				1.2	1.1	0.5						
Ave	1.64	1.18	0.68	1.17	0.58	0.30	1.38	0.79	0.54	2.76	1.63	1.31	1.54	1.30	1.10

*In = Influent An = Anaerobic Al = Algae

APPENDIX F-3

Total Nitrogen, Mg/1 as N

Day	Aug			Sep			Oct			Nov			Dec		
	In *	An*	Al *	In	An	Al	In	An	Al	In	An	Al	In	An	Al
1	7.1	2.0	1.5				3.2	4.2	4.2						
2										3.6	3.9	3.8			
3	8.3	1.6	1.4	3.6	3.3	2.8	6.0	2.2	4.3				7.1	6.0	5.3
4															
5				4.5	3.3	3.6	4.3	3.3	3.7	10.5	5.6	4.9	6.4	5.6	11.0
6	9.5	1.8	1.0												
7				6.6	4.1	4.1				8.1	5.8	2.5	6.9	5.6	4.8
8	--	2.9	2.3				3.9	3.9	4.0						
9										9.5	5.6	5.6			
10	3.5	2.0	1.8	4.6	3.8	3.6	2.9	3.0	4.3				7.1	6.5	7.7
11															
12				8.3	4.7	4.8	5.6	3.4	3.0	8.8	7.3	8.4	10.7	4.2	6.4
13	3.1	3.1	3.2												
14				4.9	4.6	4.3				15.1	6.6	6.0	5.6	5.9	5.6
15	4.0	1.9	1.9				4.6	4.9	4.6						
16										10.2	5.3	5.3			
17	6.2	2.0	1.6	4.7	4.9	3.5	3.3	4.6	3.9				8.8	5.6	5.3
18															
19				3.2	1.1	1.7	3.5	3.5	4.2	8.8	7.4	6.0	--	6.7	3.9
20	3.4	2.5	1.5												
21				5.7	4.1	4.6				10.5	5.6	5.9			
22	5.6	2.7	2.0				6.0	4.1	5.0						
23										7.4	6.0	5.3			
24	6.8	3.7	3.6	7.7	4.5	11.2	6.3	4.9	5.3						
25															
26				2.1	3.5	3.9	4.2	4.3	5.5	9.8	8.3	6.4			
27	3.9	2.7	1.8							10.1	7.1	6.9			
28				2.4	3.5	2.7									
29	7.3	2.9	1.7				5.3	4.9	3.8						
30										8.1	6.3	3.9			
31	4.2	4.2	0.0				7.7	3.6	4.5						
Ave	5.6	2.6	1.81	4.85	3.78	4.23	4.77	4.22	4.30	9.28	6.21	5.44	7.53	5.77	6.25

*In = Influent An = Anaerobic Al = Algae

APPENDIX F-4

Soluble Phosphate Mg Per Liter as P

Day	Aug			Sep			Oct			Nov			Dec		
	In *	An *	Al *	In	An	Al	In	An	Al	In	An	Al	In	An	Al
1	3.3	4.0	2.5												
2										1.4	0.8	0.3			
3	2.8	5.1	2.2	0.5	0.5	1.4	0.2	2.2	3.0				0.4	1.0	22.1
4															
5				0.3	0.6	0.5	3.0	3.1	0	4.5	4.3	0.1	0.5	0.4	19.0
6	3.5	6.4	2.0												
7				0.7	0.8	0.2				4.8	8.6	10.1	0.1	0.2	12.9
8	--	10.8	5.4				0.1	0.04	0.2						
9										0.1	0.0	3.0			
10	1.9	20.3	7.6	0	0	0	0.0	5.8	.03				0.4	0.5	0.5
11															
12				1.1	0.1	0.3	0.0	0.0	0.4	0.6	0.9	2.8	1.7	0.4	0.6
13	--	26.9	11.1												
14				0.2	0.0	2.0				0.1	2.4	1.0	0.9	0.3	0.2
15	0.9	25.7	15.0				1.0	0.6	0.6						
16										0.0	0.1	2.8			
17	0.5	23.6	13.2	1.3	6.1	1.1	0.5	0.2	0.1				0.0	0.1	0.7
18															
19				0.4	0.7	1.6	0.1	0.4	0.2	1.2	0.2	9.1	--	0.5	0.4
20	0.9	20.4	17.8												
21				0.6	0.3	0.4				1.0	0.1	11.5			
22	0.5	16.0	11.2				0.8	1.4	1.1						
23										1.9	0.5	17.6			
24	0.9	10.7	4.7	0.5	4.8	3.1	3.1	0.7	0.6						
25															
26				2.2	10.2	6.1	0.4	0.7	0.1	0.4	0.4	25.2			
27	0.5	10.1	2.5							0.9	0.1	14.3			
28				0.2	0.6	0.3									
29	2.4	5.9	2.9				0.4	0.3	0.2						
30				2.2	1.8	3.2				3.5	0.2	22.5			
31	0.3	8.8	4.1				0.6	0.4	0.2						
Ave	1.5	13.9	7.3	.78	2.04	1.57	0.79	1.25	.54	1.53	1.43	9.3	0.57	0.43	7.1

*In = Influent An = Anaerobic Al = Algae

APPENDIX G

Microbiological Activity

G-1 Daily Algal Cell Counts

G-2 Daily Algal Cell Packed Volume

G-3 Count and/or Incidence of Daphnia

G-4 Count and/or Incidence of Rotifers

G-5 Count and/or Incidence of Purple Sulfur Bacteria

G-6 Gas Emission

APPENDIX G-1

Algal Counts Cells Per ml x 10^{-6}

Day	Aug		Sep		Oct		Nov		Dec	
	An *	Al*	An	Al	An	Al	An	Al	An	Al
1	.140	.385			.137	.900	.680	.867		
2	.195	.325	.347	.448	.495	.855	.940	1.10	.220	2.19
3	.170	.370	.320	1.70	.190	.600			.396	1.67
4			.300	1.50	.537	.877	.300	.400	.38	1.31
5	.111	.300	.200	1.89	.410	1.28	.695	.750	.540	1.72
6			.102	2.78*			.72	.175	.636	1.75
7	.162	.400	1.90	3.30	.710	.895	.22	.30	.163	2.40
8	.175	.250			.380	1.10	.177	.170		
9	.420	.580	.395	.935	.447	.735	.500	.520	.600	.980
10	.500	.780	.440	2.30*	.600	.910			.686	.990
11			.392	2.10	.635	.840	.742	.860	.630	.985
12	.067	.242	.250	1.07	.315	.400	.966	1.50	.583	.916
13	.067	.475					.210	.580	.200	.528
14	.042	.425	.785	2.12	.587	.657	.710	.922	.150	.510
15	.190	.750			.445	.735	.220	.720		
16	.150	.810	.420	1.02	.637	.907	.600	1.09	.170	.470
17	.120	.820	.310	.750	.630	.775			.200	.410
18			.300	.630	.400	.425	.320	.860	.163	.340
19	.095	.215	.220	.730	.275	.785	.230	.904		
20	.260	.760	.230	.560			.490	1.02		
21	.480	.620	.840	1.110	.190	.790	.507	1.03		
22	.270	.870			.760	.907	.310	1.003		
23	.112	.870	.400	0.77	.695	1.02	.100	2.50		
24	.330	1.17	.172	0.87	.295	.630				
25			.160	0.53	.430	.680	.310	1.20		
26	.500	2.22	.115	0.66	.377	.583	.250	2.12		
27	.400	1.40					.372	1.48		
28	.366	1.04	.480	0.62	.767	.872				
29	.250	0.85			.660	.740	.475	1.31		
30	.300	0.76	.700	0.740	.192	.412	.050	0.97		
31					.200	.375				
Mean	.235	.645	.425	1.266	.459	.766	.444	.974	.382	1.001

*An = Anaerobic pond effluent   Al = Algae pond effluent

APPENDIX G-2
Algal Solids Packed Wet Volume Mg/L

Day	Aug		Sep		Oct		Nov		Dec	
	An *	Al*	An	Al	An	Al	An	Al	An	Al
1	.42	.59			.62	1.84	1.05	.56		
2	.45	1.08	.5	2.25	.60	1.20	.6	.96	.25	.16
3	.63	0.72	.45	2.07	.5	2.40			.28	2.25
4			1.26	1.44	.6	2.52	.85	.90	.24	.27
5	.70	1.62	0.78	2.45	.6	1.87	.56	.90	.12	1.2
6	.35	.56	1.08	3.24			.66	.80	.35	1.9
7	.35	.47	0.60	2.35	.45	1.05	.36	.57	.48	1.62
8	.35	1.08			.20	2.10	.60	.90		
9	.24	.90	0.60	2.85	.16	1.50	.27	1.20	.35	.38
10	.25	1.71	.75	3.60	.37	4.5			.15	.18
11			.80	1.87	.24	2.0	.40	.60	.64	1.90
12	.60	1.9	1.05	3.60	.75	2.28	.80	.85	1.7	1.6
13	.15	1.14	.25	3.20			.45	.42	.33	1.35
14	.40	0.97	.30	2.16	.45	1.75	.73	.42	.94	1.5
15	.10	1.25			.40	1.50	.56	.45	2.2	0.4
16	.48	.90	.65	2.00	1.2	2.56	.75	.60		
17	.51	1.17	.84	2.00	.37	0.60			2.4	0.45
18			1.1	2.6	.25	1.25	.85	.84	2.4	0.56
19	.14	.99	0.6	.24	.10	1.25	1.12	0.60		
20	.70	.90	.75	1.49			1.26	1.20		
21	.52	.60	.27	2.10	.30	1.70	0.40	1.80		
22	.45	1.42			.60	1.75	0.42	0.42		
23	.68	1.17	.87	1.80	.25	1.50	0.90	2.25		
24	.54	1.35	.75	1.1	.20	3.25				
25			0.5	1.3	1.0	2.40	.61	.25		
26	.25	2.1	0.8	1.6	.21	0.76	.55	2.85		
27	.30	1.62	0.4	1.62			.24	2.10		
28	.21	1.35	.25	0.84	.12	.60				
29	.54	1.80			.15	.45	0.6	4.5		
30	.24	1.90	.62	.75	.5	1.5	.35	2.25		
31	.25	1.35			.2	.70				
Ave	.40	1.20	.67	2.02	.420	1.69	.64	1.17	0.85	1.05

*An = Anaerobic pond effluent   Al = Algae pond effluent

APPENDIX G-3

Daphnia, Organisms Per Ml

Day	Aug		Sep		Oct		Nov		Dec	
	An**	Al**	An	Al	An	Al	An	Al	An	Al
1	*	*								
2	*	*								
3	*	*								
4										
5				*						
6		*		7						
7										
8										
9	*									
10			2.5							
11										
12		*								
13										
14										
15	*	20								
16										
17	*	*								
18										
19					*	*				
20	*	*								
21	*	*								
22										
23										
24										
25										
26	*	*								
27										
28										
29										
30										
31										

*Indicates presence in sample but not enumerated
**An = Anaerobic pond effluent Al = Algae pond effluent

APPENDIX G-4

Rotifera Cells Per Ml x 10^{-6}

Day	Aug		Sep		Oct		Nov		Dec	
	An *	Al*	An	Al	An	Al	An	Al	An	Al
1					--	--	--	--	--	--
2					.012	.000	--	--	--	--
3					.000	.000	--	--	--	--
4					.005	.042	000	.300[1]		
5					--	--	--	--	--	--
6			.02	.037	--	--	--	--	000	000
7					.000	.020	--	--	--	--
8					--	.025	--	--	--	--
9			.122	.004	.022	.020	--	--	--	--
10			.002	.012	.020	.090	--	--	--	--
11			--	.062	.030	.125	--	--	--	--
12			.005	.060	.000	.000	--	--	--	--
13			.012	.035	.000	.000	--	--	--	--
14					.000	.035	--	--	--	--
15					.025	.090	--	--	--	--
16			.002	.022	.040	.117	--	--		
17			--	.092	.045	.070	--	--		
18			--	.045	--	--	--	--		
19			--	.010	--	--	--	.005		
20			.007	.012	--	--	--	--		
21			--	--	--	--	--	.040		
22			--	--	.040	.060	--	.020		
23			--	.040	.045	.065	--	--		
24			.005	.012			--	--		
25			--	.013	.027	.028	--	--		
26			.000	TNC	--	--	--	--		
27			--	--	--	--	--	--		
28			--	--	.022	.025	--	--		
29			--	--	.175	.010	--	--		
30			--	.395[1]	.001	--	--	--		
31			--	--	--	--	--	--		
Mean	--	--	.019	.032	.027	.043	000	.022	000	000

[1] Values excluded from mean

*An = anaerobic pond effluent   Al = algae pond effluent

APPENDIX G-5

Purple Sulfur Bacteria Cells Ml x 10^{-6}

Day	Aug		Sep		Oct		Nov		Dec	
	An*	Al*	An	Al	An	Al	An	Al	An	Al
1					3.87	+				
2					0.86	+				
3					0.00	0.00				
4			+	+						
5										
6			.407							
7										
8										
9					1.29					
10			.020							
11			+							
12			0.430							
13			3.76							
14										
15										
16			+							
17			0.86							
18			+					+		
19			51.6							
20			6.4					+		
21							+	+		
22								+		
23			3.44				+			
24			3.01							
25			10.32		+	+				
26			36.5	+						
27										
28										
29										
30			+	2.58	3.01					
31					0.40					
Ave			10.61	2.58	1.57	000	--	--		

*An = Anaerobic pond effluent   Al = Algae pond effluent

APPENDIX G-6

Gas Emission From Anaerobic Pond As Measured by Bronson[1] Collector and Wet Meter (liters/day)

Day	July	Aug	Sep	Oct	Nov	Dec
1		--	--	*	0.62	--
2		--	1.51	*	--	0.01
3		--	1.65	*	--	0.00
4		--	4.32	*	0.50	0.00
5		0.90	1.38	--	1.05	0.10
6		0.70	1.28	--	0.76	0.0
7		1.56	--	*	0.86	--
8		1.06	--	*	1.43	--
9		1.70	1.11	*	--	0.0
10		--	0.98	*	--	0.1
11		--	1.40	3.10	0.86	0.1
12		1.71	1.12	--	0.47	0.2
13		1.71	0.63	--	0.49	0.0
14		1.71	--	1.97	0.02	--
15		1.50	--	1.97	0.04	--
16		1.55	*	2.15	--	0.0
17		--	*	2.04	--	
18		--	*	0.98	0.02	
19		1.50	*	--	0.04	
20		1.50	*	--	0.01	
21		--	--	2.20	0.01	
22		0.90	--	1.87	0.01	
23		1.10	*	0.05	--	
24		--	*	0.09	--	
25		--	*	1.10	0.01	
26		0.28	*	--	0.01	
27		2.33	*	--	0.00	
28		0.96	--	0.03	--	
29		1.77	-	1.14	0.01	
30		1.83	*	1.14	--	
31	--	--	--	1.14	--	
Ave	--	1.38	1.54	1.42	0.36	0.05

*Wet Meter Inoperative

Collector Constant: To convert liters per collector day to cubic feet per acre per day, multiply by 171.

APPENDIX H

Algal Species Occurrence

H-1 August Anaerobic Pond

H-2 September Anaerobic Pond

H-3 October Anaerobic Pond

H-4 November Anaerobic Pond

H-5 December Anaerobic Pond

H-6 August Algal Pond

H-7 September Algal Pond

H-8 October Algal Pond

H-9 November Algal Pond

H-10 December Algal Pond

APPENDIX H-1

August - Anaerobic Pond - Algal Species Occurrence

Algal Species	Day																																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	NO	%
Oscillatoria	+		+		+	+	+	+	+	+		+	+	+	+	+	+	+		+	+	+	+	+	+		+	+	+		+	25	92
Scenedesmus	+	+			+				+	+					+	+	+	+		+	+	+	+	+	+		+	+	+	+	+	20	74
Chlorococcum	+																						+									2	7
Nitzchia	+	+	+		+	+	+	+	+	+		+		+	+	+	+	+		+	+	+	+	+	+		+	+		+	+	25	92
Chlorella	+	+	+		+	+	+	+	+	+		+	+	+	+	+	+	+		+	+	+	+	+	+		+	+	+	+	+	27	100
Euglena		+	+		+	+	+	+	+	+		+	+	+	+	+	+	+					+		+		+	+		+	+	21	78
Phacus		+	+						+	+							+	+		+		+			+		+	+	+	+	+	14	52
Fragilaria								+															+									2	7
Anabaena									+	+										+	+	+	+									8	30
Pyrobotrys										+					+							+	+	+	+		+					7	26
Stigeoclonium																																	
Actinastrum																																	
Coelastrum																																	
Cyclotella																																	
Tetraedron																																	
Closterium																																	
Ankistrodesmus																																	
Selenastrum																																	
Anabaenopsis																																	
Navicula																																	
Chlorococconeis																																	
Vocystis																																	
Microspora																																	
Gomphosphaeria																																	
Microcystis																																	
Stephanodiscus																																	
Palmella																																	
Gomphonema																																	
Staurastrum																																	

APPENDIX H-2

September - Anaerobic Pond Algal Species Occurrence

Algal Species	Day																																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	No.	%
Oscillatoria	+			+	+			+	+	+	+	+	+		+	+	+	+	+			+	+	+	+				+			19	87
Scenedesmus	+				+	+		+	+		+	+	+		+	+		+		+		+	+	+			+		+			17	77
Chlorococcum																																	
Nitschia	+			+	+	+		+	+	+	+	+	+		+	+	+	+	+	+		+	+		+		+		+			21	96
Chlorella				+	+	+		+	+	+	+	+	+		+	+	+	+	+	+		+	+	+	+		+		+			21	96
Euglena	+				+	+		+	+	+	+		+		+	+	+	+	+			+	+	+								16	73
Phacus	+					+				+	+								+								+					6	27
Fragilaria																																	
Anabaena											+	+																				2	9
Pyrobotrys					+			+	+	+	+	+	+						+													8	36
Stigeoclonium																																	
Actinastrum								+	+	+	+	+	+				+	+	+			+	+						+			12	55
Coelastrum																																	
Cyclotella											+																					1	5
Tetraedron											+																					1	5
Closterium													+						+					+					+			4	18
Ankistrodesmus													+											+	+							3	14
Selenastrum													+																			1	5
Anabaenopsis													+																			1	5
Navicula								+	+				+										+									4	18
Chlorococconeis				+				+	+		+	+			+		+		+													8	36
Oocystis																																	
Microspora																																	
Gomphosphaeria																																	
Microcystis																																	
Stephanodiscus																																	
Palmella																																	
Gomphonema																																	
Staurastrum																																	

APPENDIX H-3

October - Anaerobic Pond Algal Species Occurrence

Algal Species	Day																																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	No.	%
Oscillatoria	+	+		+			+	+	+			+							+					+		+				+	+	12	86
Scenedesmus	+	+	+		+				+			+							+					+		+						9	64
Chlorococcum																																	
Nitzchia		+	+	+	+			+	+			+							+		+			+		+				+	+	13	93
Chlorella	+	+	+	+	+		+		+			+							+		+					+				+	+	13	93
Euglena	+		+	+			+	+	+												+			+							+	9	64
Phacus					+														+					+								4	29
Fragilaria																																	
Anabaena																																	
Pyrobotrys																																	
Stigeocconium																																	
Actinastrum	+	+	+	+			+	+	+															+						+	+	10	71
Coelastrum																																	
Cyclotella									+																							1	7
Tetraedron																																	
Closterium																								+								1	7
Ankistrodesmus																																	
Selenastrum																																	
Anabaenopsis																																	
Diatoma		+																						+						+	+	4	29
Chlorococconeis																																	
Oocystis																																	
Microspora																																	
Gomphosphaeria																																	
Microcystis																																	
Sephanodiscus																																	
Palmella									+																							1	7
Gomphonema																																	
Staurastrum																																	

APPENDIX H-4

November - Anaerobic Pond Algal Species Occurrence

Algal Species	Day																																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	No.	%
Oscillatoria		+		+			+												+							+						5	50
Scenedesmus		+				+		+							+															+		5	50
Chlorococcum																																	
Nitschia		+		+		+	+	+							+				+							+						8	80
Chlorella		+		+		+	+	+	+						+				+							+				+		10	100
Euglena		+				+	+								+																	4	40
Phacus																																	
Fragilaria																																	
Anabaena																																	
Pyrobotrys																																	
Stigeoclonium																																	
Actinastrum								+											+													2	20
Coelastrum																																	
Cyclotella																																	
Tetraedron																																	
Closterium								+																								1	10
Ankistrodesmus																																	
Selenastrum																																	
Anabaenopsis																																	
Navicula																			+													1	10
Chlorococconeis																																	
Oocystis																																	
Microspora																																	
Gomphosphaeria																																	
Microcystis																																	
Stephanodiscus																																	
Palmella																																	
Gomphonema																																	
Staurastrum																																	

APPENDIX H-5

December - Anaerobic Pond Algal Species Occurrence

Algal Species	Day																																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	No.	%
Oscillatoria						+				+			+																			3	100
Scenedesmus													+																			1	33
Chlorococcum																																	
Nitzchia										+																						1	33
Chlorella										+			+																			2	67
Euglena										+																						1	33
Phacus													+																				
Fragilaria																																	
Anabaena						+																										1	33
Pyrobotrys																																	
Stigeoclonium																																	
Actinastrum													+																			1	33
Coelastrum																																	
Cyclotella																																	
Tetraedron																																	
Closterium																																	
Ankistrodesmus																																	
Selenastrum																																	
Anabaenopsis																																	
Navicula																																	
Chlorococconeis													+																			1	33
Oocystis																																	
Microspora																																	
Gomphosphaeria																																	
Microcystis																																	
Stephanodiscus																																	
Palmella																																	
Gomphonema																																	
Staurastrum																																	

APPENDIX H-6

August - Algal Pond - Algal Species Occurrence

Algal Species	Day																																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	No.	%
Oscillatoria	+		+	+		+	+	+	+	+		+	+	+	+	+	+		+	+	+	+	+	+		+	+	+	+		+	25	92
Scenedesmus	+	+		+		+			+	+		+	+		+	+	+		+	+	+	+	+	+		+	+	+	+	+	+	23	85
Chlorococcum	+					+							+																			3	11
Nitzchia	+	+	+	+		+	+	+	+	+		+	+	+	+	+	+		+	+	+	+	+	+		+	+	+		+	+	26	96
Chlorella	+	+	+	+		+	+	+	+	+		+	+	+	+	+	+		+	+	+	+	+	+		+	+	+	+	+	+	27	100
Euglena	+	+	+	+		+	+	+	+	+		+	+	+	+	+	+		+	+	+	+	+	+		+	+	+		+	+	26	96
Phacus	+	+	+				+		+	+						+	+		+	+	+	+				+	+	+	+	+	+	18	67
Fragilaria								+																								1	4
Anabaena									+				+			+	+				+	+				+						7	26
Pyrobotrys													+	+						+	+	+		+			+					7	26
Stigeoclonium																																	
Actinastrum																																	
Coelastrum																																	
Cyclotella																																	
Tetraedron																																	
Closterium																																	
Ankistrodesmus																																	
Selenastrum																																	
Anabaenopsis																																	
Diatoma							+																+									2	7
Chlorococconeis																																	
Oocystis																																	
Microspora																																	
Gomphosphaeria																																	
Microcystis																																	
Stephanodiscus																																	
Palmella																																	
Gomphonema																																	
Staurastrum																																	

APPENDIX H-7

September - Algal Pond - Algal Species Occurrence

Algal Species	Day																															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	No.	%
Oscillatoria		+			+	+			+	+	+	+	+	+		+		+		+			+	+	+	+				+	17	77
Scenedesmus		+				+	+		+	+	+	+	+	+		+	+	+	+	+			+	+	+	+		+		+	20	91
Chlorococcum					+	+			+	+	+	+	+			+	+	+	+					+							12	55
Nitzchia		+			+	+	+		+	+	+	+	+	+		+	+	+	+	+			+	+		+		+		+	20	91
Chlorella					+	+	+			+	+	+	+	+		+	+	+	+	+			+	+	+	+		+		+	20	91
Euglena		+			+	+	+			+	+	+	+			+	+	+	+	+	+		+	+	+	+					18	82
Phacus		+			+	+	+			+		+	+						+		+							+			11	50
Fragilaria																																
Anabaena											+	+	+						+	+	+		+		+						8	36
Pyrobotrys					+				+	+	+																					
Stigeoclonium																							+									
Actinastrum									+	+	+	+	+			+	+	+		+			+	+						+	12	55
Coelastrum																							+	+	+	+					4	18
Cyclotella											+	+								+											3	14
Tetraedron													+			+			+												3	14
Closterium																+			+				+			+					4	18
Ankistrodesmus													+							+			+	+	+						5	23
Selenastrum													+																		1	5
Anabaenopsis													+																		1	5
Diatoma					+	+							+																		3	14
Chlorococconeis						+				+	+	+	+			+															6	27
Oocystis									+			+																			2	9
Microspora									+																						1	5
Gomphosphaeria									+			+																			2	9
Microcystis											+	+							+												3	14
Stephanodiscus											+	+	+							+											4	18
Palmella												+											+	+							3	14
Gomphonema													+																		1	5
Staurastrum																																
Carteria																				+											1	5

APPENDIX H-8

October - Algal Pond Algal Species Occurrence

Algal Species	Day																															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	No.	%
Oscillatoria	+	+		+			+	+	+			+							+		+			+		+				+	+	13	87
Scenedesmus	+	+	+		+				+			+							+		+			+		+				+	+	12	80
Chlorococcum				+																				+								2	13
Nitzchia		+	+	+	+		+	+				+							+		+			+		+				+	+	13	87
Chlorella	+	+	+	+	+		+	+	+			+							+		+			+		+				+	+	15	100
Euglena	+	+	+	+			+	+	+												+			+		+				+	+	12	80
Phacus				+	+							+							+							+						5	33
Fragilaria																																	
Anabaena		+																														1	7
Pyrobotrys																																	
Stigeoclonium																																	
Actinastrum	+	+	+	+			+	+	+															+						+	+	10	66
Coelastrum									+																							1	7
Cyclotella									+																							1	7
Tetraedron																																	
Closterium		+																						+								2	13
Ankistrodesmus																																	
Selenastrum																																	
Anabaenopsis																																	
Diatoma		+	+				+	+													+			+						+	+	8	53
Chlorococconeis																																	
Oocystis																																	
Microspora																																	
Gomphosphaeria																																	
Microcystis									+																							1	7
Stephanodiscus																																	
Palmella																																	
Gomphonema																																	
Staurastrum																																	

APPENDIX H-9

November - Algal Pond Algal Species Occurrence

Algal Species	Day																															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	No.	%
Oscillatoria		+		+				+							+				+							+					6	60
Scenedesmus		+		+		+		+							+				+							+				+	8	80
Chlorococcum						+	+												+							+					4	40
Nitschia		+		+		+	+	+							+				+							+				+	9	90
Chlorella		+		+		+	+	+	+						+				+							+				+	10	100
Euglena		+		+		+	+	+							+				+							+					8	80
Phacus		+																	+							+					3	30
Fragilaria																																
Anabaena																																
Pyrobotrys																																
Stigeoclonium																																
Actinastrum							+	+											+												3	30
Coelastrum																																
Cyclotella																																
Tetraedron																																
Closterium																																
Ankistrodesmus		+																													1	10
Selenastrum																																
Anabaenopsis																																
Diatoma							+								+											+					3	30
Chlorococconeis																																
Oocystis		+																													1	10
Microspora																																
Gomphosphaeria																																
Microcystis																																
Stephanodiscus																																
Palmella																																
Gomphonema																																
Staurastrum																																

APPENDIX H-10

December - Algal Pond Algal Species Occurrence

Algal Species	Day																																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	No.	%
Oscillatoria						+				+			+																			3	60
Scenedesmus						+	+						+	+																		4	80
Chlorococcum																																	
Nitzchia							+			+			+	+																		4	80
Chlorella						+	+			+				+																		4	80
Euglena						+				+																						4	80
Phacus						+	+						+																			3	60
Fragilaria																																	
Anabaena						+							+																			2	40
Pyrobotrys																																	
Stigeoclonium																																	
Actinastrum													+																			1	20
Coelastrum																																	
Cyclotella																																	
Tetraedron																																	
Closterium																																	
Ankistrodesmus																																	
Selenastrum						+																										1	20
Anabaenopsis																																	
Diatoma													+																			1	20
Chlorococconeis																																	
Oocystis																																	
Microspora																																	
Gomphosphaeria																																	
Microcystis																																	
Stephanodiscus																																	
Palmella																																	
Gomphonema																																	
Staurastrum																																	